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MEETINGS AND PAPERS

BIRMINGHAM DISTRICT SECTION

E. P. WINTERS, *Chairman* BIRGER THELE, *Secretary*

Saturday, October 27th **Birmingham, Ala.**

"Electric Arc Welding," by J. D. Wright, Ind. Engr. Dept., General Electric Co., Schenectady, N. Y.

CLEVELAND DISTRICT SECTION

G. A. LAMBERTON, *Chairman* A. R. LINTERN, *Secretary*

Thursday, October 18th **Electric League Rooms, Hotel Statler, Cleveland, O.**

"Union Terminal Electrification," by W. A. Pinkerton, Asst. Elec. Engr., Union Terminal Co., Cleveland, Ohio.

PHILADELPHIA DISTRICT SECTION

GEORGE PFEFFER, *Chairman* L. O. MORROW, *Secretary*

Saturday, November 3rd **Engineers Club, Philadelphia, Pa.**

"Starting Characteristics of Large Synchronous Motors," by H. H. Angel, Gen. Foreman, Elec. Dept., Bethlehem Steel Co., Sparrows Point, Md.

"Ward Leonard Equipment Applied to Blast Furnace Skip Hoists," by E. L. Anderson, Gen. Foreman, Elec. Dept., Bethlehem Steel Company, Sparrows Point, Md.

CHICAGO DISTRICT SECTION

J. J. BOOTH, *Chairman* GORDON FOX, *Secretary*

Tuesday, October 23rd **Chicago, Ill.**

Inspection Trip, South Works, Illinois Steel Co., Chicago, Ill.

"The Electrical Plant at South Works," by W. S. Hall, Elec. Engr., Illinois Steel Co., S. Chicago, Ill.

PITTSBURGH DISTRICT SECTION

R. B. DAVENPORT, *Chairman* JOHN F. KELLY, *Secretary*

Saturday, November 17th **William Penn Hotel**

"Factors in Designing Motors Involving Proper Selection of Carbon Brushes."

EDITORIAL

Elimination of Waste Through Improved Material Handling

Steel denotes strength, bigness, immense forces. It carries with it powerful machinery, large investments, great tonnages and great wastes. These wastes appear as shrinkages of material, losses due to inaccuracies of products, heat losses, power losses, waste labor. This last appears simply as the unavoidable overhead.

The first are so large that the last seems small. In any individual case the waste may be small on a percentage basis, but this small percentage multiplied by the principal becomes something more than appreciable.

Waste labor generally means too many men doing a piece of work. Conversely it means one man doing less than it can be made possible for him to do, still without exceeding his physical and mental capacity.

Material handling conveys to the steel mill operator's and engineer's mind the thought of his large cranes, roll tables, belt conveyors, locomotives and self-propelled trucks. These have been designed for a specific job. The more nearly a straight line job, the better the designing. The automotive plant engineer has developed a straight line of production carrying with it the immensities of the steel mill, but eliminating the wastes consisting of surplus labor.

The successful accomplishment of the large tasks of material handling have occupied the steel mill executive's mind to the exclusion of the large variety of small savings possible through improved material handling. These small savings can aggregate to the entire steel industry a tremendous total.

On the blast furnace floor, not all plants are equipped for efficient handling of spouts, mud gun, mud and other materials needed quickly.

Back of the gas producer, ashes should be disposed of economically as well as in the boiler-house.

The small mill sometimes feels it cannot afford improved coal handling.

Some rod-mills use small bundles instead of the larger, heavier bundles made possible by material handling development.

In the machine shop, armature shop and plant foundry it may not be considered worth while to include the necessary devices so that one man can do the work formerly done by two.

In an alloy steel plant, a crane operator, two laborers and weigh master carefully add overhead to every thousand pounds of steel made ready for shipment.

In a rod mill, two weigh masters in close proximity help prevent the speedy movement of materials.

The machine shop is arranged so that the fifteen ton crane, spanning the entire shop, can help pick up 200 pound loads. It is possible this same load might be more efficiently handled by a one ton Gantry without a crane operator. How is it economical to continuously propel a crane weighing 15 tons with the additional expense of a crane operator when a crane weighing 1.5 tons without a special operator can handle the 1,000 pound loads, which are 95% of its duty?

Windows are provided, but allowed to become blackened by reason of lack of proper economical and safe cleaning facilities.

A certain manufacturer boasts of employing only skilled mechanics having eliminated his labor gang by mechanical handling equipment.

Improved material handling is a relatively new science probably not more than five years old. During this five years the industrial executives have been seeking ways and means to reduce costs already low, having already curtailed every other avenue of expense. New and better ways of doing even small things are eagerly sought although a few years ago these operations were considered economical.

A variety of devices and material handling improvements permit one man to do tasks formerly requiring two or more. It is a competitive mistake to cause a man to do less by lack of these devices. A change in elevation of floor or ceiling, a railroad siding or break between buildings, no longer constitute obstacles to movements of material.

Improvements by control manufacturers permit automatic dispatching of loads from one point to a number of destinations.

The steel mill engineer has evolved a heavy complex. His problems have always been big problems and his solution of them big machinery of heavy proportions, large bed plates, large bearings, large shafts, large factors of safety. He has gradually been given smaller parts of superior design and finds he can get into smaller spaces with his applications with a factor of knowledge of what he can depend on from known materials and trustworthy manufacturers. The development of light material handling equipment has been towards the use of steel of high tensile strength in order to reduce weight and the effect of impact of heavy electrically propelled loads. The same development of light high tensile strength equipment permits flexibility of installation.

The possibilities for large savings to be made up of a variety of small savings is present in every plant. A great many ideas have been developed by the workmen in every plant to make the job easier. This development will be generally a make-shift home made affair, which while it embodies the idea, lacks the refinement of detail available in equipment for the same purpose on the market.

A careful check in every plant by some member of perhaps the engineering or efficiency department will reveal a number of these ideas, which may have already been worked out in a better way in some other plant. The location of such unique labor saving devices and an interchange of ideas on the various applications will reveal unthought of possibilities to the operators of every plant. Each one can probably contribute something useful to other plants and to the industry at large.

Materials, machinery, labor and markets are alike available to all. A nationally known industrial economist believes the profits of the next five years will be those resulting from improved material handling in the minor jobs that have heretofore been considered as unimportant.

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Adjustable Speed Main Roll Drives

Mr. Marion H. Morgan, of the Engineering Department of the Carnegie Steel Company at the Edgar Thomson Plant of Braddock, Pa., has prepared for the Association of Iron and Steel Electrical Engineers and the readers of the Iron and Steel Engineer an article covering Adjustable Speed Main Roll Drives, which is of direct interest to the Executives, Operating Superintendents and the engineers of the Iron and Steel Industry.

Heretofore, when information was required in connection with adjustable speed main roll drives, it was necessary to refer to so many various sources and required so much time that the true values contained in the references were not appreciated. It, therefore, occurred to the author that the information and data available should be condensed and compiled under one heading, making it easier for the executives, the superintendents or engineers to make an analysis and arrive at a decision.

To our knowledge, this article is the first undertaking of its kind and reflects credit upon the author.

Mr. Morgan, the author, is a graduate of the University of Virginia, was associated with the general engineering division of the Westinghouse Electric & Manufacturing Company and is now employed in the Engineering Division of the Carnegie Steel Company at their Edgar Thomson Works in Braddock, Pa., and has been identified with the electrical improvements and extensions made at this plant in the past few years.

M. H. MORGAN

INTRODUCTION

THIS article is dedicated to the proposition that the reader must be served, both the executive and non-technical man and the engineer or operator. For the former there is provided in tabular form so that it is instantly available and understandable the essential facts of performance, usual application, and comparative cost for each of the practical types of alternating and direct current adjustable speed mill drives. For the latter there is in addition the necessary detailed description and explanation to make clear the operation of each and its most advantageous use.

The information in tabular form includes for different drives of the same class as well as for the different classes (1) A statement of method involved (2) A comparison of operating characteristics, performance and average cost (3) Outstanding advantages and disadvantages (4) General use.

The detailed information for each drive includes a statement of the principle involved and its application to that particular method; an outline of its operating characteristics both favorable and unfavorable; its performance, and a description and explanation of any special machines used. Diagrams, sketches, curves and pictures are used wherever possible to make a point clear with fewer words, and grouping of facts under subheads simplifies the finding of a particular one when wanted.

Figures and statements given have been checked with the manufacturers of the equipment to which they apply and it is believed that they accurately represent present practice.

PURPOSE

One-third of all the mill drives installed in this country have been variable speed and the rest constant, but during recent years the change in type of mills and the increased number of products which a single such mill is required to handle has neccessitated variable speed drive on a much greater proportion. Thus of all mill drives installed during the years 1926 and 1927 two-thirds were variable speed and one-third constant speed. It appears then that we must expect to deal mostly with variable speed drives in the present and immediate future.

A constant speed mill drive is practically always an induction or synchronous motor and standard practice for such is pretty well defined and generally known but an adjustable speed drive may be any one of almost a dozen well recognized types which differ widely in operation, performance and cost. Each of these has been completely described in various places at various times, but the widely scattered condition of this information and the varying form given it made it very difficult to compare them on any logical engineering basis or to select for a particular drive the class which will be satisfactory and the one which will be most satisfactory and most economical.

It is the intention of this article to provide in as concise form as possible the essential information contained in these scattered ones, to bring it up to date and to give it an arrangement and form that will make it easy to compare any particular class of drives with any other, or one of a type with another of the same type or to locate and assimilate the complete description of a particular drive.

Arrangement Of Material

The article deals with direct current adjustable speed drives of the various types, the several methods of obtaining more than one speed from standard induction motors without auxiliary machines, and with the so-called dynamic regulating systems (Scherbius, Kramer and Frequency Converter), in the order named. It includes also, the brush shifting A.C. variable speed motor.

First is the portion dealing with direct current drives and following it a tabular comparison of the four types described.

Next are the five methods of obtaining several speeds from the standard induction motor without auxiliary machines, (such as the use of resistance in the secondary of a wound rotor machine, or the variation of frequency of power supply). At the end of this section is a tabular comparison of each of these methods with dynamic regulating systems and with the brush shifting motor. This table should allow the user to determine which of the classes represented is required for his purpose after which he need examine the full description of only one or two.

Following this is a section devoted to explanation of the general principles and characteristics common to all three of the dynamic regulating systems and then each of the three is taken up separately and more fully. A tabulation at the end of this compares the three systems.

The brush shifting motor is the subject of the next and final descriptive section, so placed because an explanation of it is easiest made when based upon that of the dynamic regulating systems.

Finally there is a tabulation and brief statement of the essential factors to be considered in choosing between Alternating or Direct current for a given drive.

For students and those who wish to pursue the subject further there is a bibliography from which references much of the material included here has been obtained or checked.

DIRECT CURRENT ADJUSTABLE SPEED DRIVES

The first application of motors to main roll drives in this country consisted of two installed in 1906 on a light rail mill at the Edgar Thomson Works of the Carnegie Steel Company. These motors were direct current and provided adjustable speed between 100 and 125 R.P.M. by field control. It may be of interest to note that these drives are still giving excellent service and are operated most of the time near the upper limit of their range. Since that time, there have been almost three times as many alternating current drives installed as D.C. because in addition to the practically universal use of A.C. for drives when constant speed is permissible, there have been developed the highly satisfactory types of alternating current adjustable speed drives to be described later.

But during the past two years the development and increasing use of the modern high speed mills with individually driven stands rolling a number of different products has so increased the proportion of D.C. drives sold that **there were installed during that time actually more D.C. than A.C. drives.**

This fact, as indicating the general trend, makes it worth while to consider in some detail the characteristics and application of the various forms of D.C. adjustable speed drives.

Adjustment of the speed of the ordinary shunt or compound wound D.C. motor is accomplished (1) By adjustment of motor field strength (2) By variation of impressed armature voltage (3) By combination of these two methods, and (4) By armature resistance control.

ADJUSTMENT BY FIELD CONTROL

This is the simplest and most widely used of all methods, for moderate speed adjustments will require only a field rheostat in addition to the equipment used with a constant speed D.C. drive, and there is no change in the method of operation. The change of speed with load for a standard shunt machine is small compared to that obtained with adjustable speed A.C. drives and it may be made as small at any speed as is required by the use of one of the separate exciter schemes while the performance over any part of a moderate speed range is practically as good as that of a constant speed machine.

Rating

When the speed of a D.C. machine is varied by weakening the field and the voltage is kept constant the current capacity of the machine is not changed. The efficiency is constant within the limits of one or two percent and neglecting the decreased ventilation at lower speeds we may say that such a machine is inherently a constant horsepower drive.

Compensating Windings

When the motor field has been weakened to obtain the higher speeds the effect of armature reaction is to distort the field and affect unfavorably both commutation and motor speed regulation and in some cases machine stability under load. For this reason a mill drive having a range of 2:1 or greater will usually have a so-called "compensating" winding. This is a series winding so placed in the face of the main poles that it corrects and compensates for the effect of armature reaction at all loads and speeds.

Speed Regulation At High and Low Speeds

Many drives have some series field turns and where the speed range is large or the change of speed with load must be small, adjustment of the amount of these series ampere turns must be made when going from a low to a high speed as will be shown. The series field produces a change in speed with load by reason of the fact that it changes the amount of field flux as the current in the series winding increases or decreases with load. The amount of this change when the motor speed is a minimum and the shunt field correspondingly at its maximum strength is fixed by the design characteristics of the machine. When the

speed is increased by weakening the shunt field the proportion of the total excitation supplied by the shunt field at full load is decreased and that supplied by the series winding increased. If the load now be reduced from full load to zero it is evident that the change of total excitation and hence of speed will be greater than when the speed was low and the shunt field strong.

Methods of Obtaining Close Speed Regulation With Compound Wound Machines

Several methods are used for adjusting the series field strength to correspond to weakened shunt field. The most common and also the simplest is to shunt the series field or parts of it with low resistance grids as the speed is increased. If this method is used one or two changes of series field ampere turns would be made, depending upon the range of speed adjustment and accuracy of control desired for the whole speed range. It is, therefore, an approximation only of the correction desired.

A more exact method for use where the range is wide is the employment of a series exciter in connection with an extra field winding of the shunt type fed from this machine.

This exciter is a small D.C. generator whose field winding consists of a few turns of the armature leads

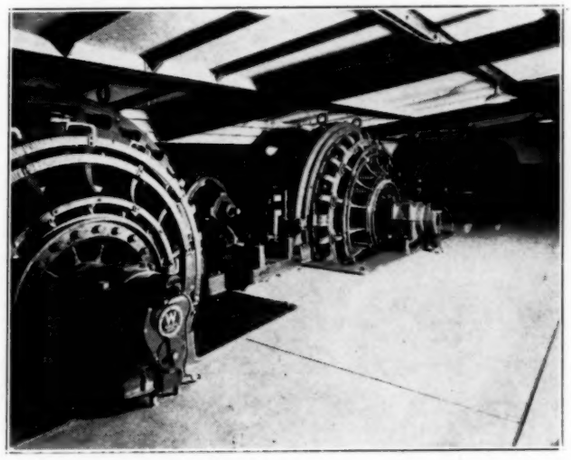


FIG. A—DC Field Control Motors on Finishing Stands of Hot Strip Mill. Note knife switches on motor frame for adjusting strength of series field turns.

of the main motor or which is excited from the commutating winding of the main motor. In either case, its field and therefore the voltage it supplies is proportional to the load current. One method of using this equipment is the employment of an extra rheostat in this series-excited field, mechanically coupled to the shunt field rheostat and having its steps proportioned by test to give the proper amount of series excitation at all speeds. A slightly different employment of apparatus is to have the series exciter in the regular shunt field circuit, connected to "buck" the regular excitation voltage, and make no adjustment of the series winding as the speed is increased. It may be shown that this will accomplish the same result if the design characteristics of the machine are known and taken into account in proportioning the series winding and the voltage of the series exciter.

Automatic Speed Control Devices

Field variation of D.C. machines lends itself very readily to automatic speed control. The field strength may be controlled by a motor operated rheostat or by Tirrill regulator type vibrating relays and thus the speed of the main motor fixed and controlled by some other piece of apparatus. One application of this principle is the use of a Tirrill type regulator in the field of a motor driving the last four stands of a rod mill to maintain a pre-determined speed ratio for these stands with that of the steam engine driving previous stands. A somewhat similar device maintains the proper speed relation between successive stands of a strip mill. The speed of forced and induced draft D.C. motor driven fans for a steam boiler is often controlled through motor driven field rheostats to maintain automatically certain pressures in the firebox in response to the operation of regulators.

This regulating equipment may be built to maintain a predetermined speed with an accuracy of a fraction of one percent where this is necessary, but of course it adds to the cost and complications of a drive.

Power Source

Any constant voltage source of power may be used to feed machines which use field control. This would include motor-generator sets or rotary converters or a mill network supplied from both, and supplying other loads as well as the particular drive whose speed must be varied. Voltage fluctuations on such a network will of course affect the speed of mill motors fed from it and where these fluctuations are wide or the mill speed must be steady it is usually necessary to cut loose the converting machinery supplying a mill drive from that for general plant service. However, for the general case, this arrangement is not necessary.

Speed Range

D. C. Main Roll Drive Motors are commonly built having speed ranges up to 2:1. Some are built with 3 to 1 range obtained by field control alone and even

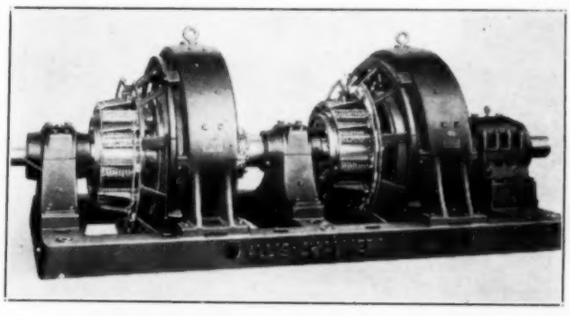


FIG. B—Double Armature DC Mill Drive.

4:1 in some cases of twin armature construction. Motors for the larger speed ranges require special mechanical and electrical construction and their cost is considerably higher therefore. Also the wide speed range sometimes compels the designer to sacrifice some of the stability and peak load capacity of the smaller range motor to obtain this large adjustment of speed.

ARMATURE VOLTAGE (WARD LEONARD) CONTROL

Voltage control of speed is practically never used alone but nearly always in conjunction with field control on the same motor. Where frequent and rapid reversals are necessary, voltage control is usually used because this provides full motor torque for acceleration and retardation and then the same equipment which provides for speed control will, with little change, provide for rapid reversals under full control of the operator.

Horsepower Varies With Speed

The field excitation remaining constant the speed of a D.C. motor will vary directly with the applied armature voltage. The current capacity does not change nor does the torque vary. Therefore, we may say that this method of speed adjustment provides a constant torque drive in which the horsepower varies directly with the speed.

Equipment Required—Speed Regulation

It involves the employment of a separate D.C. generator for each motor or group of motors whose speed may be varied together; separate excitation to provide full field for the motors and reduction of generator excitation and voltage.

Since the motor field strength is not changed its commutation and peak load capacity are not affected. The field of the generator being weakened its commutation tends to be affected by armature reaction just as is that of a motor whose speed is increased by field control and usually a compensating winding is applied.

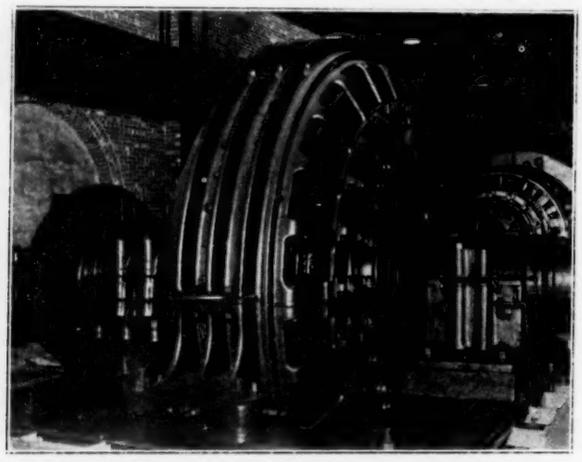


FIG. C—Reversing Type Mill Motor for Ward Leonard Control. Note rugged mechanical structure.

When a low operating voltage is used the voltage drop in the leads and connections becomes a large percent of the applied voltage and results in greater change of speed with load. If a compound wound generator be used having a heavy series field, then at very low operating voltage it will have characteristics approaching that of a series generator and will thus give the motor a characteristic which is highly undesirable for most mill drives. For example, if the generator field be so proportioned that at full load 10% of its excitation be supplied from the series turns and it be operated at 20% of normal voltage at no load, the application of full load will increase the voltage of the generator to 30% of normal and speed up the motor 50%. Such a motor characteristic as increasing speed with load is unstable and could not be used with safety. To take care of this condition, generators so used are usually arranged to cut out their series fields for such operation.

Power Source

When Ward-Leonard control is used it is necessary to provide separate generators or M-G sets for each motor or group of motors whose speed may be varied together. Separate excitation is also necessary for both motors and generators, since the method involves the lowering of the operating voltage of both and prevents its use for excitation purposes.

This also prevents the use of rotary converters or the general mill D.C. network as a power source for such drives.

Control Equipment

The control equipment must provide for the isolation of the power source of these drives from others and take care of the separate excitation source. However, once the generator and motor armatures are connected, practically the entire control operation is confined to their field circuits, and since the currents

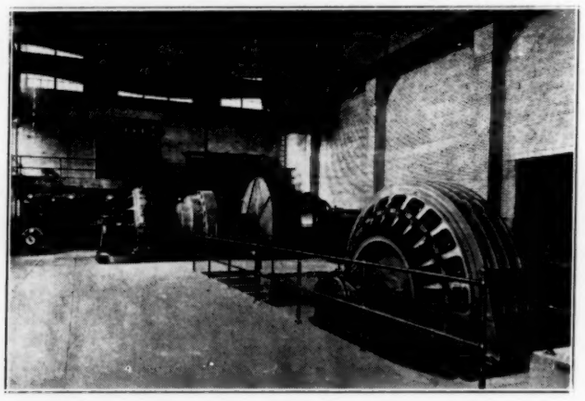


FIG. D—Reversing Type Mill Motor for combination field and voltage control. Note flywheel MG set in background.

in these circuits are small the equipment to do this is fairly simple and no larger than that used on auxiliaries.

Motors arranged for Ward-Leonard control may be started very simply from rest by slowly bringing the generator voltage up to normal with a hand or motor operated field rheostat, thus eliminating the contactors and grids used for resistance starting. The voltages employed are low (250 to 700) and the current capacity and cost of these contactors and resistors is correspondingly high, so that the saving enjoyed when they are not required is often a large item.

Speed Range

The upper limit of speed control by this method, is of course the rated full field normal voltage speed of the motor, while the lower limit is a creeping speed of two or three RPM. Mention has already been made of the fact that at very low voltages and speeds

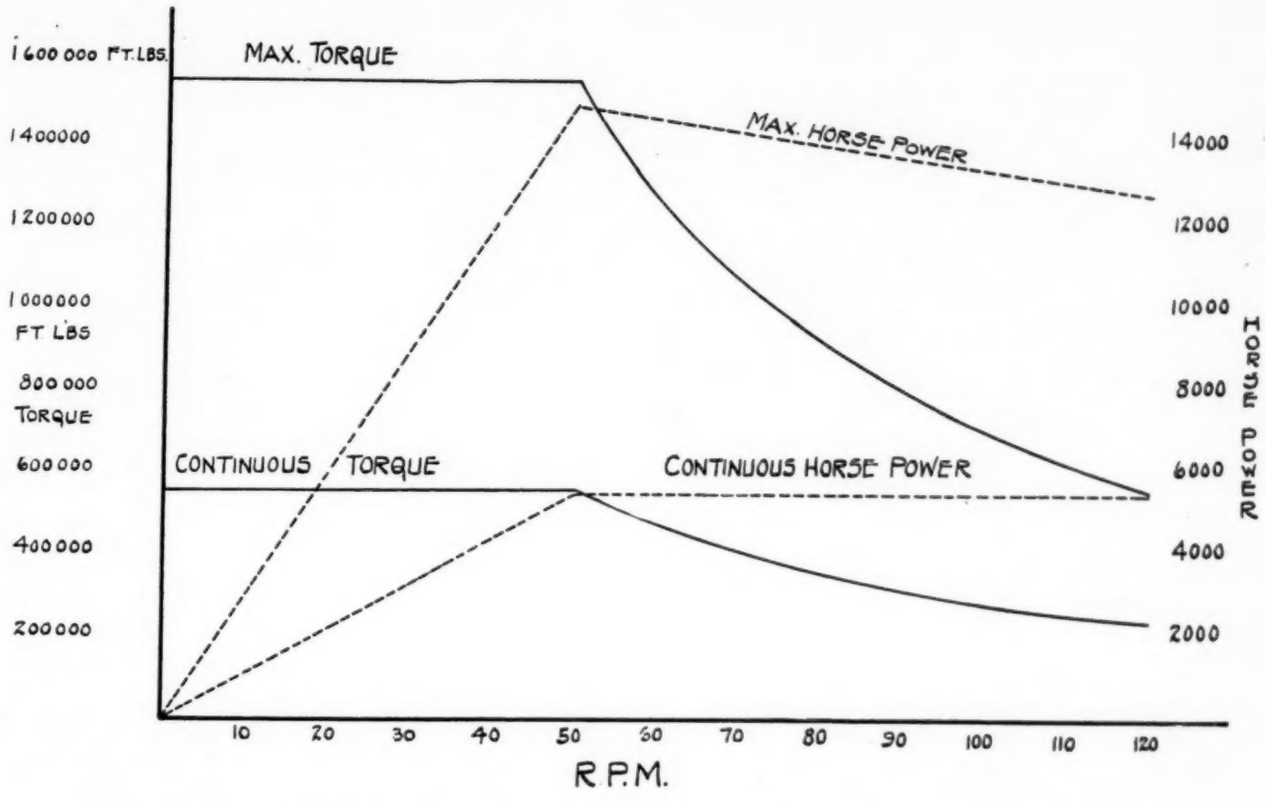


FIG. 1—Curve showing horse power and torque at various speeds for motor using combination Ward Leonard and Field Control.

the series turns of the generator must be shunted or otherwise rendered inoperative, and that the voltage drop in the leads becomes quite a large proportion of the applied voltage and gives rise to poor speed regulation but with these limitations in mind the machine may be operated successfully at practically zero speed.

Forced ventilation is usually necessary if the machine is to be operated at very low speeds for then the natural ventilation produced by the movement of the armature is insufficient.

COMBINATION ARMATURE VOLTAGE (WARD-LEONARD) AND FIELD CONTROL

This is usually the most expensive but the most flexible method of providing adjustable speed. It provides the widest speed range of any, and allows of quick reversals or rapid changes of speed with full motor torque, all under complete control of the operator. Since it is a combination of two methods, whereby the lower portion of the speed range required is obtained with armature voltage control and the upper portion by field control it necessarily includes the major advantages and disadvantages of each. Thus armature voltage control is a method of obtaining motor speeds below the rated full field normal voltage speed while field control provides speeds above this value, and the combination of these two methods makes it possible to obtain any required value between a creeping speed of 2 or 3 RPM and the maximum safe weakened field speed at which the machine may be operated. This usually represents a range of from 40 to 50:1.

Horsepower and Torque Ratings

It is necessary to consider the horsepower and torque requirements separately at each speed for both are varied with speed and in a different way for the two methods of control.

Fig. 1 shows this variation of torque and speed for a nominally rated 5500 HP 50 RPM mill motor on which speeds from zero to 50 RPM were obtained by variation of armature voltage and from 50 to 120 RPM by field weakening. Inspection of the curve shows that the motor is capable of delivering a rated constant torque up to 50 RPM and a HP increasing directly with speed up to this point, while above 50 RPM the motor horsepower remains constant and the torque falls off inversely as the speed. For the sake of indicating the effect of each method upon the peak load capacity of the motor, curves are also shown of maximum torque and maximum horsepower under the same conditions. It will be observed that up to 50 RPM the maximum values vary with the nominal or continuous rated values, while above this both the maximum HP and maximum torque fall off more rapidly than the continuous ratings. This is largely due to the effect of armature reaction upon commutation at the higher speeds when the shunt field has been weakened.

Saving In Motor Size

When the power requirements of a mill at various speeds approximate the capacity which this method provides at those speeds, as they frequently do this combination method gives a distinct economy in motor size.

Assume that 1000 HP is required for a given drive with a speed range of 300 to 450 RPM and that it is also necessary to obtain a speed of 200 RPM for the rolling of certain sections with full load torque or less. By applying two-thirds of full rated voltage to the motor armature and full motor field the machine rated 1000 HP at 300 RPM may be run at 200 RPM and will deliver 667 HP and full load torque at this speed. To obtain this entire range with field control alone would require a motor rated about 990 HP at 200 RPM which would be almost 50% larger and more expensive.

Power Source—Control

The fact that a portion of the range is covered by Ward-Leonard control makes it necessary to provide separate generators or M-G sets for each motor or group of motors whose speed may be varied together, and prevents the use of synchronous converters or the mill D.C. network as a power source. It also requires that the control equipment isolate the power source from other sources and necessitates separate excitation for both motors and generators.

The control for both motors and generators is practically confined to their field circuits, once their armature circuits are connected, so that the control equipment is fairly simple and handles only small currents. It is also possible to start the motors by bringing the generator voltage up slowly and do without all starting resistors and contactors. This item frequently represents a considerable saving and of course simplifies the control.

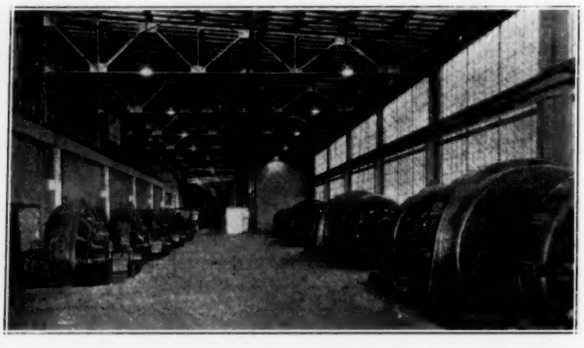


FIG. E—DC Field Control Motors Driving Tandem Finishing Stands of Strip Mill. Synchronous M-G sets shown at right. Mill motors rated 2000 H-P 200/400 RPM.

Speed Regulation—Cost

The speed regulation at the various parts of the range covered are about the same as given for the individual methods used to attain that speed. Thus it is poor at low speeds, good at speeds close to full field, full voltage speed and again poorer, although still good at high speeds reached by field control.

The overall cost of such a drive is usually high, because of the necessity of providing separate generators, but where those provided are for some other reason separate anyway, it is a very economical method, for the general case. For many special kinds of drives it is the only method which will fulfill the requirements. Some of these are described in greater detail later.

ARMATURE RESISTANCE CONTROL

As previously stated, if the field excitation be kept constant the motor speed will vary directly with the applied armature voltage and where the necessary reduced voltage is not available direct, it may be obtained by inserting resistance in series with the armature.

This method makes available speeds below the full field speed of the motor without the use of a separate generator and thus finds a use on existing drives for an emergency or when the full field speed is too high for some products not originally contemplated. It would hardly be considered good practice for a new drive, because of its poor efficiency and unfavorable speed-load characteristics.

Speed Regulation Poor

When the load current increases, the voltage drop in the resistor increases proportionately so that the resultant voltage across the motor armature is decreased and the motor speed with it. Thus if the motor speed is being held 30% below normal at full load with armature resistance, an increase of load to 200% for an instant will bring the speed down to 60% below normal while if the load be reduced to a small value the motor speed will rise to practically the same value it would have without any such resistance. This is practically a series characteristic and is not well adapted to mill drives.

Loss of Efficiency

The reduction in efficiency with this method is proportional to the speed reduction obtained. At 50% of normal speed 50% of the power taken from the line is dissipated as heat in the resistance and not only does no useful work but must be carried away from the resistor by some means of ventilation.

Effect on Motor Capacity—Limits of Range

Since the motor operates with full field its commutation is not affected.

The motor becomes a constant torque drive and its horsepower capacity is reduced proportionally with the speed. Thus a 1000 HP 500 RPM motor operating with armature resistance sufficient to reduce its speed to 400 RPM when the drive requires full load torque will at this speed take 1000 HP from the line, deliver 800 HP in load torque to the mill and waste 200 HP in the resistor.

It is usually not practical to reduce the speed further than about 20-30% because the fluctuation in speed from full load to no load is even then very large and if more resistance is used there is danger of stalling the mill on peaks. Thus if the motor named above have sufficient armature resistance to reduce its speed at full load to 250 RPM, (50% nor-

mal) a peak of 200% load will stall it while at light load the speed will rise practically 100%.

Control—Cost

While no actual additional control equipment is required for this method other than the standard resistance starter with its accelerating contactors and grids yet usually these contactors and grids must have additional capacity if used for this purpose.

This represents the entire extra cost of obtaining reduced speed from a constant speed D.C. drive by this method, and for small reductions the standard controller will often serve without change.

Special Applications of D.C. Adjustable Speed Drives

There are some well recognized special uses for armature and field controlled motors which are worthy of more detailed description. Among these are the two high reversing bloomer, some three high structural and plate mills and many of the new bar and strip mills.

Three High Structural and Plate Mills

A three high structural mill handling large and long pieces will require a relatively slow speed for entering the piece properly in the rolls and with the usual type of drive this would be the limiting speed

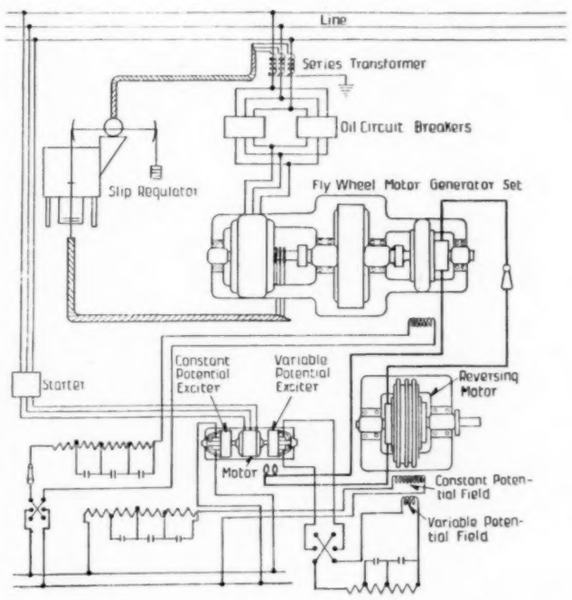


FIG. 2—Schematic Diagram of Single Unit Reversing Mill Equipment.

of the mill and consequently the limit on its tonnage. After the piece is entered the remainder of the pass may be made at a much higher speed if the drive be of a type to provide this speed and have sufficient reserve capacity to furnish the necessary torque for acceleration in addition to that required for rolling the steel.

Fig. 2 shows the main connections for such a drive employing Ward-Leonard and field control. It comprises a separate flywheel motor generator set and separate excitation for each drive and means for controlling the excitation of both the generator and mill motor to obtain rapid changes of speed. It is practically the same drive as is used for two high reversing mills and is considerably more expensive than the simpler and more common type. Its justification is largely increased tonnage on mills for which it is adapted.

Any one of several slow speeds for entering the piece are obtained by applying full field to the motor and controlling the field of the generator to give any one of several low voltages. This allows the motor to furnish full load torque at either of these speeds and since both it and the generator are designed for momentary peak loads from two to three times their continuous rating they will handle successfully the peaks imposed by quick acceleration with a piece in the rolls. Intermediate speeds are obtained by building the generator field and voltage up to its operating maximum, usually 600 to 700 volts, and the higher speeds with full armature voltage by weakening the motor field. A lighter draft is taken on finishing passes and the full motor torque is not required so that the characteristic of decreased torque at higher speeds obtained when weakening the motor field is permissible.

The field of both motor and generator is controlled indirectly through magnetic contactors and relays operated by the motor armature current allow the drive to be accelerated automatically at the maximum safe rate. The mill may also be brought to a quick stop or reversed by the control, which by strengthening the motor field and weakening the generator field causes the drive to regenerate and pump power back into the line, the relays meanwhile keeping the value of this current within safe limits. A variation of this control sometimes used is a foot operated push button which will bring the mill speed down to a proper value for entering the piece and when released will automatically accelerate the mill to a speed determined previously for that particular section being rolled.

This type of drive will usually be fed from what is known as an "Ilgner Set," that is a motor-generator set having a rather large flywheel and a driving motor of the wound rotor induction type with a slip regulator in its secondary. This slip regulator is essentially a large liquid rheostat which through the action of current relays in the induction motor power leads automatically inserts a greater resistance in the motor secondary circuit when the motor load current tends to exceed the value for which the regulator is set. The regulator may be set for a given amount of line power and when so set will absolutely limit the amount of power taken from the system, whatever peaks the motor may demand. The slowing down of the flywheel M-G set in response to the slip regulator operation will force the flywheel to give up its energy for those peaks and then when the peak has passed the amount of power taken from the line remains at the regulator setting until the flywheel has been brought up to speed again. Where the capacity of the individual drive is a large portion of the generating capacity or where purchased power is used, this feature is of great advantage in limiting the peak demand.

Strip and Bar Mills

Many of the new strip and bar mills having individually driven finishing stands use DC motors on these finishing stands, obtaining speed variation by a combination of Ward-Leonard and field control. On some such mills, Ward-Leonard control is supplied to be used for starting only for the sake of the greater simplicity of starting equipment and the saving in cost, while all speed adjustment is made with field control.

The finishing passes on these mills are usually so long that no advantage may be gained from the use of flywheels and consequently the motors are supplied from synchronous motor driven M-G sets.

Reversing Mills

Reversing mills and the drives for them are so highly specialized that they can hardly be classed as an adjustable speed drive. The thing that makes them elaborate and costly is the necessity for quick reversals and speed adjustment happens to be an easy matter when the control for reversing has been provided.

The fundamental type of drive for reversing mills is that already described for a three high structural mill. On this arrangement are based many variations, including double armature motors fed from two generators in parallel. All use the combination Ward-Leonard—field control; most are fed from an induction motor driven flywheel M-G set and all both start, stop and reverse the main motor by control of the fields of it and its generators without opening or reversing the armature circuits.

The motor is ordinarily very slow, 40 to 75 RPM full field, full voltage speed and attains a maximum of 100 to 150 RPM by field control. It will be force ventilated and will be constructed especially to provide large peak load capacity in comparison to its continuous rating. Thus such a drive may be capable of delivering three times its normal continuous rated torque and horsepower for load peaks of short duration. Its mechanical construction must be correspondingly rugged and the generators must have the same peak current capacity as the generator. Both motors and generators will have commutating and compensating fields.

VOLTAGE OF D. C. DRIVES

D.C. main roll drive motors are usually built to operate on either 250 volts or some voltage between 500 and 750. The standard for machines above 500 HP for other than reversing mills may be said to be 600 volts and for smaller machines 250.

For large capacity machines the copper required in connections is reduced when the higher voltage is used and a saving thus effected. Smaller machines will normally be somewhat cheaper when designed for 250 volts.

Sometimes it is necessary or desirable to be able to use the M-G sets provided for the proposed mill drive for supplying power to the mill D.C. network or to operate the mill drive from this network and since practically all mill general purpose D.C. systems are 250 volts, this fixes the mill motor voltage at once.

Reversing mill drives usually have an M-G set which is used for nothing else and by reason of its control cannot be fed from another set. The power circuits between this M-G set and its motor are thus short and confined to the one building and the choice of voltages may be made solely to suit the machines themselves. Accordingly, the manufacturer ordinarily fixes this at the value which will allow him to get the most out of his motor and generator and it may vary from 600 to 750 volts.

CONVERTING MACHINERY

Most mills use synchronous motor driven M-G sets to provide D.C. power, because they usually need the power factor correction effect of an .8 leading p.f. machine to offset their induction motor load and because the M-G set offers a certain flexibility of voltage supply and consequently better paralleling characteristics.

Some rotary converters are used, but relatively few and the mercury arc rectifier has not yet come into use in this industry.

Where the plant A.C. distribution voltage will permit of connecting the motor of the M-G set direct without transformers as is usually the case, the cost of the set will be practically the same as that of the converter with its transformers. The efficiency of the latter will be a few per cent higher, but its D.C. delivery voltage can only be changed by changing the A.C. voltage supplied, which is not easily done in most cases, and the converter may be operated only at unity power factor, while the synchronous M-G set will usually be built for 80% power factor leading.

Reversing mills are usually supplied from an induction motor driven M-G set to utilize the effect of the flywheel of the set and prevent the mill peak loads from reaching the A.C. Power system.

NOTES TO TABLE 1

The information given in this table is available piecemeal in many places, but is given this form here so that an engineer contemplating the use of one or another of the types named may have before him at the one time for quick appraisal the essential facts concerning each. Thus he is enabled to survey the field and pick one or two methods as the probable best choice and then examine that one or two in greater detail in other parts of this same article if necessary, but he is saved the time and trouble of going through the full description of all.

The figures given and statements made simply represent present economical practice for the average case. It is possible to name exceptions to almost every figure or statement in this table, but such exceptions to the general rule almost invariably represent either an experiment or an expensive departure from the standard which may or may not be justified by the results attained.

These figures and statements have been checked with the manufacturers and are accurate for the general case although future developments may change them in many particulars.

TABLE I—COMPARISON OF DIRECT CURRENT VARIABLE SPEED DRIVES

	FIELD CONTROL.	ARMATURE VOLTAGE (Ward-Leonard) Control	ARMATURE RESISTANCE CONTROL	COMBINATION WARD-LEONARD AND FIELD CONTROL
SPEED RANGE.	Limit about three to 1. 2:1 is limit for standard construction.	From creeping speed of one or two rpm up to full field full voltage speed.	20-30% reduction below full field speed.	From creeping speed of one or two rpm to two or three times full field full voltage speed. 40 or 50:1.
SPEED REGULATION.	About 2-4% on 2:1 range machines of standard construction, but can obtain 1% if necessary over this range. Zero regulation possible with regulating devices.	Somewhat poorer than for field control.	Poor—Speed rises to normal at light load.	Poor at creeping speeds. As good as 1 or 2% near full field full voltage speed and can be held this low over upper portion of range with special construction, but normally somewhat higher at top speeds.
HORSEPOWER RATING.	Constant over entire range.	Reduced proportionally with speed.	Reduced proportionally with speed.	Constant torque (HP varies with speed) up to full field full voltage speed and constant horsepower above this point.
SEPARATE EXCITATION.	Not necessary.	Necessary for motor and generator	Not required.	Necessary for both motor and generator.
COMMUTATION AND PEAK LOAD CAPACITY.	Decreased at upper limits of range.	Not affected	Commutation not affected. Load torque limited because motor may stall on peak.	Motor commutation affected near limits of range covered by field control.
STARTING.	Resistors and contactors necessary.	Requires no resistors nor contactors.	Contactors and resistance required.	Contactors or starting resistors not required.
POWER SUPPLY.	Any D. C. source—Mill Network, Converters, or M-G set.	Requires separate generator or M-G set for each drive or group of drives whose speed is varied together. Converters cannot be used.	Any D. C. source, M-G set, converter or D. C. network.	Requires separate generators or M.G. set for each drive or group of drives whose speed may be varied together. Converters cannot be used.
CONTROL.	Simple. Field rheostat only in addition to starting equipment.	Must include means for isolating drive and its generator from others and for controlling separately excited generator fields.	Additional steps and greater capacity required of contactors and starting resistor.	Differs from standard. Must include equipment for isolating drive and its generator from others and for controlling separately excited fields of both motor and generator.
DISADVANTAGES.	(1) Full field speed of motor is lower limit. (2) Effect upon peak load capacity and commutation at extremes of range.	(1) Necessity for using separate generators for each drive. (2) Horsepower capacity is reduced with speed. (3) Poor speed regulation at low speeds. (4) Additional cost.	(1) Poor speed characteristics. (2) Poor efficiency. Efficiency is reduced directly with the speed. (3) Additions to resistors and contactors. (4) Reductions in horsepower capacity.	(1) Necessity for providing separate generators for each drive. (2) Additional cost. (3) Necessity of separate excitation. (4) Reduced HP capacity at low speeds and reduced peak load capacity at very high speeds requires exact knowledge of load.
ADVANTAGES.	(1) Simplicity of method. (2) No additions to switching equipment required. (3) Motors may be fed from any D. C. source. (4) Lends itself easily to automatic speed regulation from some other machine.	(1) Quick changes of speed or reversals possible. (2) No starting resistors or contactors in armature circuit. (3) Makes possible use of speeds too low for field control method. (4) No affect upon commutation or peak load capacity of motor. (5) Full motor torque available to maximum motor speed.	(1) Makes available speeds below full field speeds of motor without use of separate generator. (2) Simplicity. (3) No reductions in motor torque for small speed reductions.	(1) Extreme flexibility and wide speed range. (2) Quick changes of speed and reversals possible. (3) No starting resistors or contactors necessary in armature circuit. (4) Possible saving in size and cost of motor for wide range of speed.
USE.	The most widely used method of any for D. C. machines.	Seldom used alone. Usually in conjunction with field control. Best method for rapid reversals or frequent changes of speed under load.	Not good practice for a new drive. Used on existing drives where full field speed is too high for some products not originally contemplated, or in an emergency.	Widely used, particularly on the modern high speed mills rolling a wide range of products. Usually most expensive, but most flexible drive available of any type.
COST.	MODERATE	HIGH	LOW	HIGHEST

ALTERNATING CURRENT ADJUSTABLE SPEED DRIVES

Since alternating current is almost universally used for power generation and distribution in steel plants it is advantageous to use this power on mill drives with as little transformation or conversion as possible. To this consideration is added the very attractive characteristics of the standard induction motor-simplicity of construction, economy of first cost and of maintenance and good performance, and the result has been a vigorous search for ways of obtaining variable speed from the standard induction motor.

The methods developed cover a wide range of effectiveness, of cost and of principles, from the simple use of resistance in the secondary to the addition of the auxiliary machines necessary to make up a Scherbius or Frequency Converter set. Many find wide use and others only infrequent uses but all that find any practical use are taken up here for the sake of completeness.

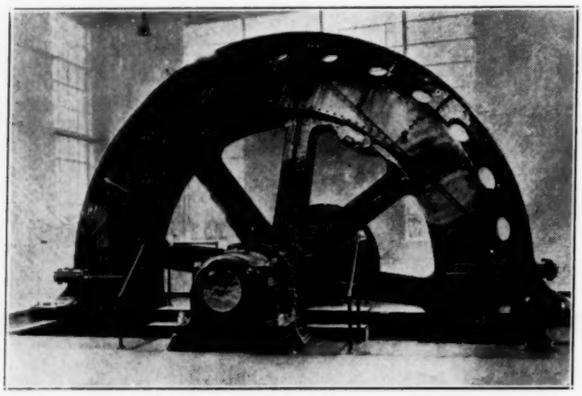


FIG. F—Slow Speed Type Induction Motor 5000 HP—99 RPM.

These may be divided into two general groups:

(1) Methods employing auxiliary machines, also known as Dynamic control systems—
Kramer Sets
Frequency Converter Sets
Scherbius Sets.

(2) Methods not employing auxiliary machines—
Variation of Line Frequency
Varying Motor Pole Number
Cascade Connection
Control of Primary Voltage
Secondary Resistance.

(3) A third method must also be considered, consisting of a single machine which attains the same results on a smaller scale and through the use of the same principles as the Scherbius or Frequency Converter sets—
The Brush Shifting Motor.

VARIATION OF LINE FREQUENCY

This method finds only a rare use on mills because it requires a variation in the speed of the generator feeding a drive which uses it and the isolation of this generator and motor from all other drives. This makes it difficult to apply, but it is a bona fide method and where circumstances will permit of its use will give good performance and requires no change or additions to the control. It therefore merits a brief description.

The no load speed of an induction motor may be expressed as $N = \frac{120\ F}{p}$ where "F" is the frequency of the power supply and "p" is the number of motor poles. Thus one way of controlling the speed of the ordinary induction motor is to vary the frequency of the power supply.

Rating

To avoid increasing the flux density in the magnetic circuit of the machine the voltage of the supply circuit must be raised or lowered in the same proportion as the frequency and speed. If this be done, the decrease in motor ventilation with lower speed will be about offset by the decrease in iron losses with lower frequency, and the machine will have about the same current capacity. Its normal and maximum torque will remain about the same for ordinary speed changes and the continuous horsepower capacity will likewise vary with the speed.

Speed Range—Performance

The permissible change of speed is limited to about 30-35% reduction and to increases of less than five per cent, because within these limits the speed regulation, maximum torque, and power factor are practically unchanged and the efficiency is only slightly decreased. A reduction below this usually involves a reduction in maximum torque although accompanied by an increase in starting torque. The amount by which these quantities change for a given case is a function of the design, and different for each machine.

Control

No change whatever is required in the standard controller. Since the machine concerned and its generator would be operating at different frequencies than the rest of the power system, it is necessary for the switching equipment to isolate them from other drives, or where a group drive is used whose speed may be the same, one generator may be used to serve them and the group isolated from the rest.

It will be observed that this is a somewhat similar method of speed control for A.C. machines to the well known Ward-Leonard system for D.C. motors. The major difference is that in the latter case the necessary variation of D.C. voltage is easily and simply obtained by controlling the field of the D.C. generator, while in the former, it is necessary to vary the speed of the A.C. generator to obtain the necessary variation of frequency, which is not easily done in most cases.

Applications

The expense of such special equipment together with the complications involved, has prevented its use for new main roll drives. One application is for individual roll table drives, using a fractional HP squirrel cage induction motor on the extended shaft of each roll, and a motor generator set composed of a variable speed D.C. motor driving a synchronous generator to supply power for the whole table drive. Electric ship propulsion drives use very successfully motors wound for two pole combinations and variable frequency for intermediate

speeds but the conditions are peculiar to that application.

VARIATION OF MOTOR POLE NUMBER

For some mills of limited output the additional expense of an adjustable speed drive is felt to be unjustified, yet it is necessary to roll sections requiring widely different speeds. A multi-speed induction motor is often applied in such cases, which will operate at either of two fixed speeds.

Compared to the standard single speed induction motor of the same rating at the higher speed, the two speed machine will have lower efficiency and power factor and will cost from 50% to 100% more and the controller for it will be more complicated

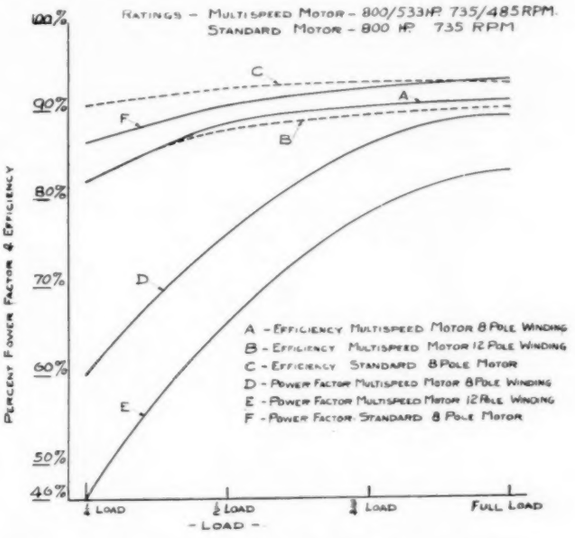

RATINGS - MULTISPEED MOTOR - 800/533HP 735/485RPM.
STANDARD MOTOR - 800 HP 735 RPM
100%
90%
80%
70%
60%
50%
46%
PERCENT POWER FACTOR & EFFICIENCY
A - EFFICIENCY MULTISPEED MOTOR 8 POLE WINDING
B - EFFICIENCY MULTISPEED MOTOR 12 POLE WINDING
C - EFFICIENCY STANDARD 8 POLE MOTOR
D - POWER FACTOR MULTISPEED MOTOR 8 POLE WINDING
E - POWER FACTOR MULTISPEED MOTOR 12 POLE WINDING
F - POWER FACTOR STANDARD 8 POLE MOTOR
¼ LOAD
½ LOAD
¾ LOAD
FULL LOAD
- LOAD -

FIG. 3—Power Factor and Efficiency of Multi-speed Motor compared to Standard Motor.

and more expensive. However, where the desired (mill) speeds may be obtained from it, it is an economical drive both in first cost and operation, a dependable one and a relatively simple one compared to the adjustable speed drives. It is commonly used on small mills of limited tonnage.

A wound rotor induction motor built for this service may have two separate primary and two secondary windings whose coils are spaced for different pole numbers, or where the speeds desired are in the ratio of 2:1 may have a sufficient number of taps brought out from a single winding to allow connection outside the machine with switches to give either of two pole combinations and speeds. The squirrel cage winding will adapt itself to any stator pole number without change so that this portion of a two speed motor of the squirrel cage induction type will be the same as that for a standard machine.

Speeds Available

It is theoretically possible to obtain more than two speeds from this type of machine, but the additional space required for the second winding in the one case and the extra leads in the other, together with the difficulty of selecting speeds bearing the proper relation to each other and to the mill requirements makes such a design impractical.

Rating—Performance

The design of a multi-speed motor is necessarily a compromise between those which would give best performance at each of the two speeds, and consequently the operating characteristics including efficiency, power factor, and maximum torque may be quite different at each of the two speeds, and not quite as good at either speed as if the machine had been designed for that one alone.

The horsepower rating at the two speeds will vary directly with the speeds, as 600/400 HP, 8/12 poles, 900/600 RPM and where increased torque is necessary at the lower speed the machine will simply be underrated at the higher speed.

Figure 3 shows typical power factor and efficiency curves for a two speed motor at both the high and low speeds and compares them with similar cases for a single speed machine of about the same rating, operating at the higher speed.

Control

The control for a single winding two speed motor having speeds in the ratio of 2:1 will have in addition to the usual provision for starting, knife switches for re-connection of its windings for either of two speeds, likewise that for a two winding two speed motor whose speeds are not in this ratio must have in addition to the usual provision for starting means of transferring from one winding to the other.

In either case this re-connection or transfer will be done with the machine at standstill and disconnected from the line.

CASCADE CONNECTION

Cascade connection affords a means of obtaining several speeds from two induction motors by interconnecting them both electrically and mechanically. It involves large reductions in the continuous horsepower capacity and maximum torque of the machines used and it is difficult to suit the speeds available to the mill requirements. It would hardly be good practice for a new drive because aside from the relatively poor performance, the machines which make it up are not used economically and the cost is consequently high. However, when its limitations are taken into account it is a bona fide method of using equipment already on hand and therefore the principal facts bearing upon its application will be set forth here.

As shown in Figure 4, the wound secondary of the first machine is connected to the primary of the second which may be of either the wound rotor or squirrel cage type, and the two are coupled together or mounted on the same shaft. The "why" of their operation is best explained by considering two machines so connected having equal pole numbers and phased out so that either considered alone would tend to start in the same direction as the other, i. e., for direct cascade or as it is also termed —direct concatenation. At the instant of starting the circuit formed of the secondary of the first motor, and the primary of the second, will have full line frequency, since the slip of the first motor is then 100%. Both motors will then accelerate until the slip of the first machine is 50% at which point the primary of the second motor will have in it half of line frequency and will operate at half

speed. The first motor cannot accelerate further because it would then have less than 50% slip, and the second motor would have to decrease its speed and slow the set down. This point is then the light speed of the set and an increase in load will act approximately equally upon the speed of both motors and slow the set down just as it would one machine operating alone.

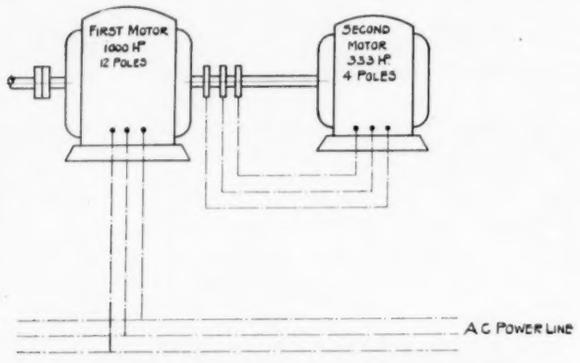


FIG. 4—Diagram for Cascade Connection.

Speeds Available

If the first machine have P_1 poles, greater than the second having P_2 poles, and they are operated upon a system of frequency "f" then the following speeds are obtainable:

$N_1 = \frac{120\ f}{P_1}$ (From first machine operating alone)

$N_2 = \frac{120\ f}{P_2}$ (From the second machine operating alone)

$N_3 = \frac{120\ f}{P_1 + P_2}$ (From the two, connected for direct cascade)

$N_4 = \frac{120\ f}{P_1 - P_2}$ (From the two connected for differential cascade.)

Division of Load Between Machines

For proportionate division of the load the ratio of the horsepower of the two motors should be the direct ratio of their pole numbers. Thus if an 8 pole machine be connected in direct cascade with a 12 pole machine, the 8 pole motor will carry 4/10 of the total load, and the other, 6/10 of the total and the ratio of their capacities should be 4 for the 8 pole motor to 6 for the other.

Control

For direct concatenation alone little addition to the standard controller is required. The secondary of the first machine is simply connected permanently to the primary of the second and only the primary of the first and secondary of the other controlled. If it is necessary to be able to operate either of the two machines separately or to run with differential concatenation additional switching equipment must be provided as well for the secondary of the first motor and the primary of the second.

Performance

The added resistance of the second machine increases the change of speed with load so that the speed regulation is somewhat poorer than for one standard machine alone. Similarly, since magnetizing current must be furnished for two machines the power factor of such a set is relatively poor and the losses of the second machine result in a relatively poor overall efficiency for the set.

Horsepower and Torque Capacity

The chief limitations of the method are the large reduction in pullout torque and continuous HP rating of each motor and the necessity of having to wind the primary of the second motor to suit the voltage characteristics of the secondary of the first motor, along with the low efficiency and power factor of the resulting drive. Thus the maximum torque of various direct cascade sets will be about as follows:

For 2 machines where $P_1 = P_2$ Less than 1/2 that of one machine.

For 2 machines where $P_1 = 8 : P_2 = 4$ Less than 2/3 that of the larger machine.

For 2 machines where $P_1 = 16 : P_2 = 4$ Less than 4/5 that of the larger machine.

SPEED ADJUSTMENT BY CONTROL OF PRIMARY VOLTAGE

Where a small speed reduction is required on an existing squirrel cage motor drive, this method is available and is relatively easy to apply. It would hardly be used for a new drive because the same effect may be obtained from a wound rotor machine, by the addition of resistance in the secondary, without the reduction of maximum torque which is involved here.

Either resistance or reactance is inserted in the primary leads so that the motor load current will cause a voltage drop in this resistance and provide reduced voltage at the motor terminals. These resistors or reactors are then simply short circuited when not in use. This reduced voltage may also be obtained direct from transformer taps when these are available.

This method is based upon the fact that for a particular machine, the torque at a given per cent slip varies with the square of the applied voltage. This relation is shown graphically in Fig. 5. "A" is a typical speed torque curve for a squirrel cage motor operating on the full line voltage for which it was designed. "B" is the same curve for this machine when operating on 80% of line voltage, and curve "C" for 60% of line voltage. The slip at full load on "A" is 3.7% and the speed 578 RPM, while on "B" the slip for this torque is 7.2% and the speed 557 RPM.

Curve "C" shows that the machine will not deliver full load torque on 60% of line voltage, although the maximum torque on full voltage is shown to be 250% of normal. The maximum reduction possible for this machine is thus shown to be from 600 to 500 RPM, and when the voltage has been reduced, the amount necessary to cause this decrease in speed the machine will barely deliver full load torque and no more. Removal of the load will, in either case, allow the motor speed to rise practically to synchronism.

Efficiency—Power Factor—Control

If resistance be used to obtain reduced voltage then the efficiency is reduced directly with the

speed, while the power factor is improved, because the voltage drop in the resistor represents a direct power loss and this portion of the total power taken from the line is at unity power factor. If reactors be used the loss of efficiency is less but the power factor will be considerably reduced.

So long as the speed range obtained is within the limits of 10% given the reduced voltage obtained from transformer taps to produce it will have little effect upon the power factor or efficiency.

The speed regulation is poor, the speed rising practically to synchronism at light load, whatever the reduction in speed at full load. The continuous horsepower capacity is reduced proportionally with the speed.

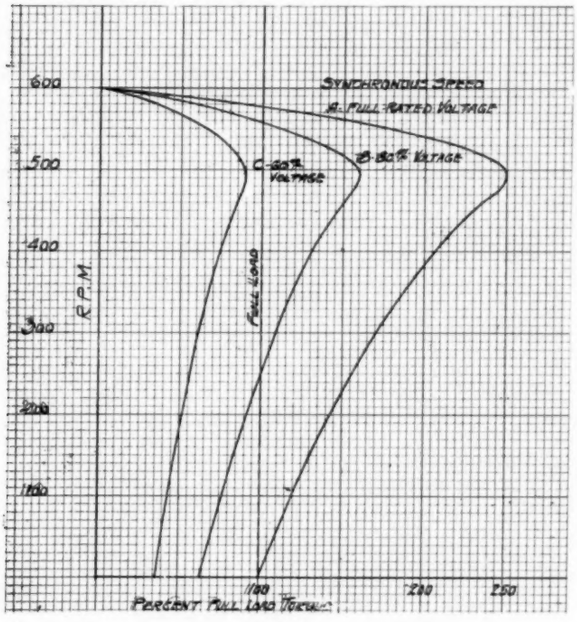


FIG. 5—Speed Torque Curves of Typical Squirrel Cage Motor with Varying Voltages and Constant Frequency.

Practically no change in control is required other than to provide some means for short circuiting the resistors or reactors when it is desired to run without them or for changing transformer tap voltages when these are used.

SPEED ADJUSTMENT BY SECONDARY RESISTANCE

This is at once the simplest and the most commonly used method of controlling the speed of a wound rotor motor. It involves no reduction in the maximum torque or power factor of the motor and requires very little addition to the control.

It is based upon the fact that the slip of a wound rotor motor at a given load is directly proportional to the secondary resistance. Figure 6 shows speed-torque curves of a given machine for various values of secondary resistance. Curve A shows the condition of no external secondary resistance, with slip rings short circuited. The motor then has a full load slip of about 22 RPM and a speed at this load of 578 RPM. Curve B shows the effect of the addition of an external resistance equal to the internal resistance of the secondary so that the total secondary resistance is twice what it was for curve A. The slip at full load is now 45 RPM and the motor speed at this load 555 RPM. If now this external resistance be increased until the total secondary resistance is 4 times that for curve A, the conditions shown for curve C will obtain, and the full load speed will be 510 RPM. Similarly curve D shows the effect of still further additions of resistance.

Performance—Speed Range

It should be noted that the maximum motor torque is not effected by these additions of resistance, although the speed at which it occurs is changed, being lower for greater values of resistance.

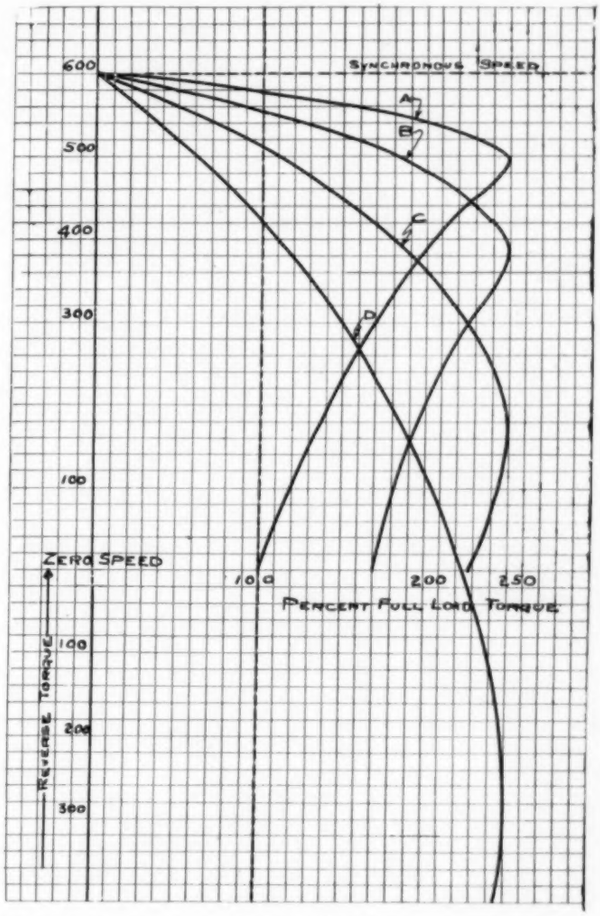


FIG. 6—Variation of Torque with Secondary Resistance.

The motor speed will rise practically to synchronous at light load, no matter what the value of resistance, and the change of speed with load (speed regulation) will be greater the more the resistance. Thus for the conditions represented by curve C, there is 17.7% speed increase from full load to no load.

The practical limit of speed reduction by this method is in the neighborhood of 40%. At this speed the efficiency of the machine is only 60% of what it would be at full speed without external resistance, because the motor is taking just as much power from the line and dissipating 40% of it as

heat in this resistor. At intermediate speeds, the efficiency is proportional to the speed. While neither the motor power factor nor maximum torque is reduced, yet the speed at which maximum torque occurs becomes lower for greater amounts of resistance, and finally the machine will deliver its maximum only when being plugged as shown in curve "D", in which case this maximum is not available for carrying load.

Motor power factor is not affected by this method, being neither decreased nor improved.

Control

No actual additional control equipment is required but increased capacity is necessary in some parts. Thus some of the accelerating contactors in the secondary circuit which are ordinarily short circuited when the machine is running must now carry full load current whenever the drive is running at reduced speed, and parts of the secondary resistance previously used only for starting must now be capable of carrying full load continuously.

Advantages and Disadvantages

The disadvantages of the method are: (1) The reduction in efficiency which becomes quite large for large speed reductions. (2) The fact that the motor speed comes back to synchronism when the load is removed, thus making the change of speed with load very large. This makes the speed of the drive erratic on a varying load and tends to give the motor a series characteristic.

The chief advantages are: (1) Low cost. It is only necessary to provide sufficient capacity in the secondary contactors and add the necessary resistance capacity. (2) Motor torque and power factor are not changed. This permits handling the same peak loads as when running at full speed and makes the use of a flywheel very effective. (3) Simplicity. No complications are introduced in the controller and a highly skilled operator is not required.

NOTES TO TABLE II

The purpose of this table is:

(1) To bring out the similarities and differences of the various methods of obtaining variable speed from induction motors without the use of auxiliary equipment and to compare these with the dynamic regulation sets (Kramer-Scherbius-Frequency Converter) and the brush shifting motor.

(2) To set down for these methods the essential characteristics which will determine their desirability or undesirability for a given purpose.

(3) To present this material in such form that it is available for instant use.

(4) To make it possible to pick out one or two methods which seem suited to the purpose and examine these further in greater detail in other parts of this article, but to avoid the need for a detailed study of all these methods.

DYNAMIC SPEED CONTROL

(Kramer, Scherbius, Frequency Converter Sets)

The principle upon which all three types of dynamic speed control sets operate is the same and it seems logical to present such part of its explanation as is common to all to emphasize this similarity before taking up each in detail. Likewise the fundamental differences between constant torque and constant HP types of Kramer, Scherbius and Frequency Converter sets and certain facts bearing upon power factor correction are common to all and are therefore put into this introduction.

Following this each set is described in detail, its peculiarities of operation, performance and construction pointed out and finally its advantages and disadvantages given.

At the end of this section will be found a tabular comparison of the three types of sets intended to allow them to be compared in the particulars usually considered most important for various types of mill drives.

Dynamic control of induction motor speed involves the use of auxiliary equipment whose function it is to suuply an additional voltage to the secondary of the motor. The auxiliary or regulating equipment automatically keeps the frequency of this applied voltage the same as that of the motor secondary and permits the fixing of its value in such a way that the speed of the drive may be adjusted, but once set, will vary only slightly with the load. It may also adjust the phase angle of this applied voltage to bring the power factor of the set close to 100%. The type and manner of use of auxiliary equipment differs for each of the sets mentioned, but in every case the main power unit is a wound rotor motor and the principle of operation is essentially the same.

The load torque of an induction motor is produced by the interaction of the magnetic field set up by the primary winding and the current in the motor secondary. This field remains constant in value and rotates at synchronous speed, and at no load the motor secondary will rotate at almost the same speed. The rotor bars will move only a little slower than the field and the voltage induced in them by reason of their being cut by the faster moving field is low and the secondary current and torque small. When full load is applied the motor slows down for lack of torque and the rate of cutting of bars by the field is increased. This increases the induced voltage in the secondary circuit, and the secondary current rises in proportion increasing the motor torque. Thus a decrease in speed takes place accompanied by increasing torque until the motor torque equals load torque and at this equilibrium point the speed is constant for a given load. In reducing the speed of a wound rotor motor by the insertion of external resistance in the motor secondary circuit, as is commonly done, the effect is to increase the induced voltage necessary to circulate a given load current. The motor then slows down until the greater difference in speed between the rotor bars and the primary field produces the required higher induced voltage to circulate that same load current through the added resistance. If instead an external voltage of the same frequency be impressed upon the motor secondary, and it be of the proper direction to "buck" the induced voltage, the machine will slow down further to reach a lower equilibrium speed for the same load, because now only the difference between the two voltages is available for circulating load current and the second current and motor torque becomes too small to carry the load. At the lower speed the induced

TABLE II—SUMMARY OF METHODS OF SPEED VARIATION FOR ALTERNATING CURRENT MOTORS

TABLE II.—SUMMARY OF METHODS OF SPEED VARIATION FOR ALTERNATING CURRENT MOTORS

	VARIATION OF LINE FREQUENCY.	VARYING MOTOR POLE NUMBER. (Multispeed Motors)	CASCADE CONNECTION.	CONTROL OF PRIMARY VOLTAGE.	SECONDARY RESISTANCE.	BRUSH SHIFTING MOTOR.	DYNAMIC REGULATION. (Kramer, Scherbius, Frequency Converter Sets).
METHOD	Vary Frequency of power supply to standard motor	Motor is built with two sets of windings, each for different numbers of poles, or single winding which is reconnected in controller for either of two speeds.	Requires use of two motors mechanically and electrically connected.	Insert resistance or reactance in leads to standard squirrel cage motor.	Insert resistance in secondary of standard wound rotor motor.	A special motor having a speed regulating winding.	Uses several auxiliary machines with a standard wound rotor motor.
MAXIMUM SPEED RANGE	About 30% reduction.	Provides several fixed speeds.	Provides several fixed speeds	About 10% reduction.	30-40% on steady loads.	3: 1	2: 1 on some types; 3: 1 on others.
CONTROL	Same as for standard motor.	Fairly simple—somewhat more equipment than for standard motor.	Requires some additions to the standard controller.	Little addition to the standard controller.	Practically no change required.	Very simple.	Special.
SPEED REGULATION	About same as for standard motor on rated frequency.	About same as for standard motor.	Somewhat larger than standard motor alone.	Poor—Speed rises to synchronous on light load.	Poor—Speed rises to synchronous on light load.	Good — Only slightly larger than standard motor.	Good — Only slightly larger than standard motor.
HORSEPOWER RATING	Reduced proportionally with speed.	Reduced proportionally with speed.	Considerably reduced.	Reduced proportionally with speed.	Reduced proportionally with speed.	Constant torque rated. Horsepower varies directly with speed.	May be built to deliver either constant torque or constant HP over entire range.
MAXIMUM TORQUE	Not affected much for 30% reduction.	About same as for standard motor.	Greatly reduced.	Greatly reduced.	Not affected for ordinary reductions.	About same as standard motor.	Maximum torque of main motor not affected while drive may be built to deliver more than that of main motor alone.
EFFICIENCY	Slightly less than for usual operation.	Slightly less than for standard motor.	Somewhat reduced.	Reduced with speed.	Reduced proportionally with speed.	Good—Only slightly less than standard motor.	3-5% lower than standard motor alone.
POWER FACTOR	Not much affected.	Somewhat less than for standard motor.	Poor.	Improved if resistance is used—reduced if reactance is used.	Not affected.	Better than standard motor at high speeds, but lower at low speeds.	Excellent — Maintains 90-95% or better at all loads and speeds.
DISADVANTAGES	(1) Requires separate power source for each drive or group of drives whose speed is varied together. (2) Requires variable speed drive for the generator furnishing power.	(1) Difficult to suit the mill requirements with the speeds available, since these must bear a certain relation to each other.	(1) Hard to suit speeds available to the mill requirements. (2) Reductions in continuous capacity and maximum torque.	(1) Large reductions in torque. (2) Series speed characteristic. (3) Losses in horsepower capacity.	(1) Series speed characteristic. (2) Losses in efficiency.	(1) Relatively high cost. (2) Limited capacity. (3) Includes A. C. commutator. (4) Special machine.	(1) Large increase in cost. (2) Includes A. C. commutator. (3) Requires more space.
ADVANTAGES	(1) Maximum torque not affected (2) Speed may be varied in several steps. (3) Requires no change in control.	(1) Simple and economical in first cost. (2) No less of torque. (3) Efficiency good.	(1) Allows use of present standard motors for other speeds. (2) Provides more speeds than a multispeed motor.	(1) Relatively easy to apply to existing drive. (2) Simplicity.	(1) Uses standard motor and control. (2) Provides full motor torque. (3) Simplicity.	(1) Good speed and torque characteristics. (2) Wide speed range. (3) No external auxiliaries. (4) Control very simple.	(1) Good efficiency, speed regulation and stability under any kind of load. (2) Wide speed range in large capacities. (3) Improves power factor.
CONCLUSION	Not a practical method for main roll drives. Used on auxiliaries.	A practical and economical method when the speeds available serve the purpose.	Practical only in special cases to make use of standard motors already on hand.	Usable method for squirrel cage motors.	The simplest and most practical method available for use with a standard motor except dynamic regulation.	Practical for small capacity drives where low voltage A. C. power only is available, speed range large and load requires constant torque.	The best A. C. method for large capacity.
USE	Rare on mills.	Commonly used on small mills.	Seldom used.	Very seldom used on mill drive.	Often used, mostly for small reductions and steady loads.	Two have been applied to main roll drives and many to auxiliaries.	Dynamic regulation or D. C. is the general practice for main roll drives having speed range of 10% or greater.
COST	Involves changes to power supply system which are usually very expensive.	Nearly double that of a standard constant speed drive having the same rating at the top speed.	Usually high for new equipment.	Relatively little when applied to existing drive.	Low.	Much higher than standard motor and higher than other methods except dynamic regulation.	The most expensive A. C. drive, the proportion increasing with the speed range.

voltage is increased until the difference between it and the impressed voltage is again sufficient to circulate the necessary load current. If the impressed voltage be of a direction to assist the induced voltage, then the secondary current and motor torque will be increased for the moment, while the motor will speed up until the decreased value of the induced voltage plus the impressed voltage is again just sufficient to circulate the necessary load current.

Figure 7 shows graphically the voltage conditions in the secondary circuit of an induction motor, while its speed is adjusted by this method in either direction from its normal full load speed. E_r represents the voltage necessary to circulate full load current, while E_m represents the voltage induced in the motor secondary, and E_i the voltage supplied by the auxiliary machines and impressed upon the motor secondary.

The value of E_r will of course change with load but to simplify the explanation, we will assume that the load torque and E_r remain constant.

The value of E_i is fixed by the excitation of one of the auxiliary machines and the speed at which the set will run thus controlled. Its frequency is automatically adjusted to be always the same as that of E_m and E_r, by methods which differ for each type of set and which will therefore be explained in the detailed description of each set.

As already stated the field set up by the primary winding revolves at synchronous speed and its value and direction of rotation do not change. The rotor coils are, at normal slip (full load speed), rotating at a speed some 2 or 3% slower than this and E_m is proportional to the amount of this difference in speed. At synchronysm there is no such difference in speed and E_m is zero. Above synchronism the rotor is moving faster than the primary field and E_m is consequently reversed in direction.

Below Normal Slip Speed

At normal slip the total induced voltage E_m is just equal to that E_r required for the circulation of full load current, and the voltage E_i supplied by the auxiliary machines is zero. To reduce the speed of the drive we apply a certain excitation to the auxiliary machine and thereby impress E_i upon the main motor secondary circuit in a direction to subtract from E_m. At the instant that this is done there remains only a small portion of E_m to circulate the load current, and the motor slows down. As it does so, the motor slip and E_m increases until the difference between E_m and E_i is gain equal to the original value of E_r. The motor speed is now stable because an increase in load means simply a decrease in speed until E_m minus E_i equals the required value of E_r and the change in speed to accomplish this is only very slightly larger under these conditions than for the main motor operating alone. In other words the speed regulation of such a drive is only one or two per cent greater than that of the main motor alone, unless it is desirable to make it so in which case it can be increased.

Between Normal Slip and Synchronous Speed

It has been stated already that at normal slip speed E_i is zero, that is, there is no excitation upon the auxiliary machines and therefore no external voltage impressed upon the main motor secondary. To increase the speed of the drive from this point, excitation is applied to the regulating machine in a direction to produce a voltage E_i opposite in direction to that which lowered the speed of the set.

This voltage therefore assists the induced voltage E_m and for the instant the secondary current and motor torque is increased beyond the load requirements so that the drive accelerates. As it does so E_m decreases in value until the sum of E_m and E_i is just sufficient to equal the former value of E_r.

At Synchronous Speed

As the value of E_i is increased by increasing the excitation of the regulating machine the motor speed rises and approaches synchronism while the value of E_m simultaneously decreases until at synchronism it has fallen to zero and E_i alone supplies the required voltage (E_r) to circulate load current.

Above Synchronous Speed

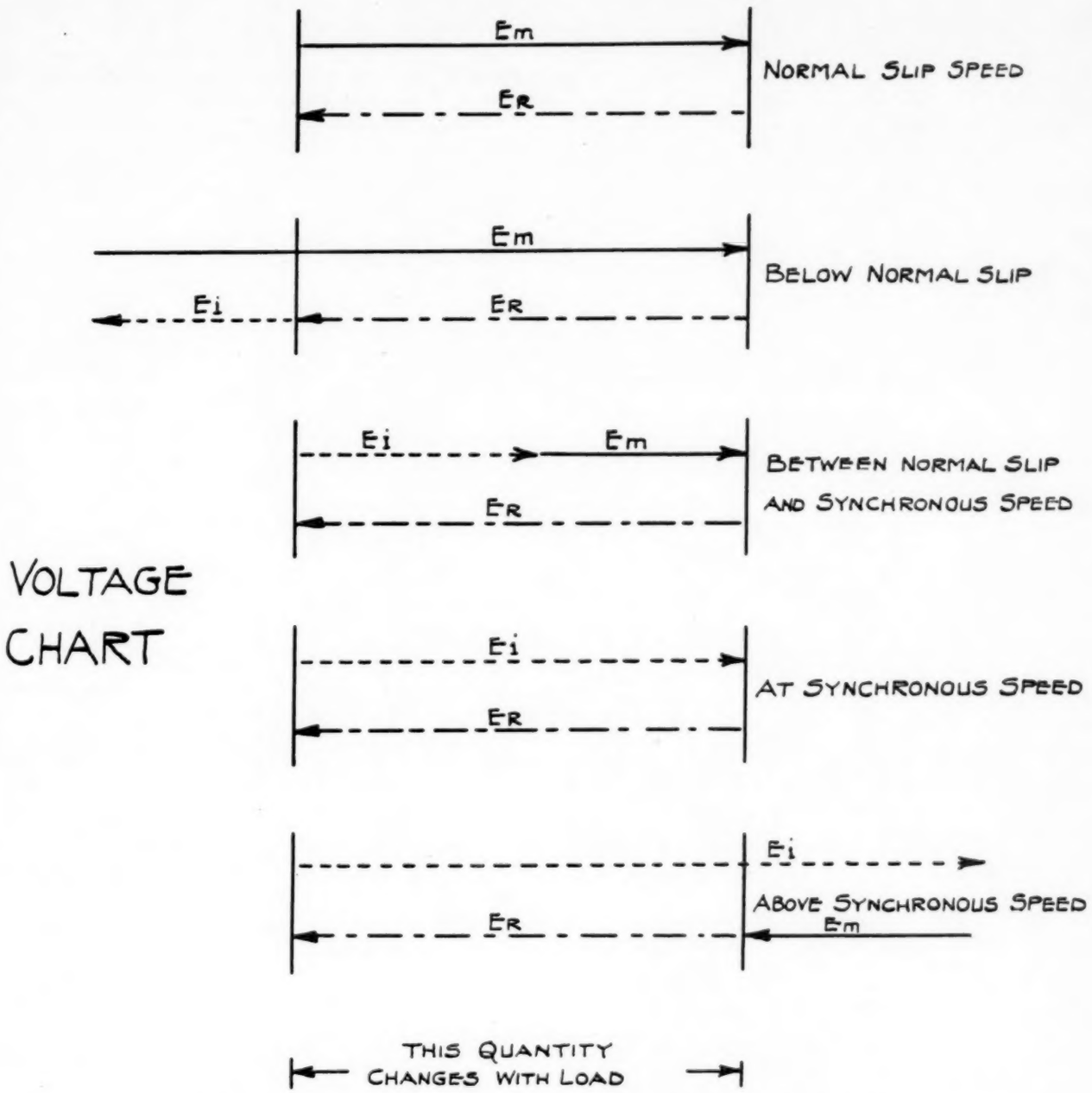
With the drive running at synchronous speed a further increase of excitation of the regulating machine increases E_i again and the main motor secondary current and torque is instantaneously increased above load requirements so that the drive accelerates. As the speed rises above synchronism E_m again appears and increases directly with the speed, but reversed in direction so that it now opposes E_i. The speed of the rotor bars in which E_i is generated is now higher than that of the primary field and the relative direction of their cutting by this field is reversed. For any given setting of the excitation of the regulating machine and therefore of E_i in this range there is an equilibrium speed at which E_i minus E_m just equals the value of E_r necessary to circulate full load current and the motor speed will be stable at this point.

It will be noted, that in going from a speed below normal slip to a speed above synchronism, both E_m and E_i have reversed, but that E_r still preserves its original direction. This shows that the main motor current has not changed direction and since the primary field has not been changed in any way the main motor torque still has the same direction.

CONSTANT TORQUE AND CONSTANT HP RATED SETS—DIFFERENCES

If a Kramer, Scherbius or Frequency Converter set is to be used for a drive requiring constant torque only throughout its speed range, then the machines which compose it are ordinarily given a certain definite arrangement, while those composing a drive which must deliver constant HP over its full range, are given a different arrangement. For reasons of economy in manufacture, the types are sometimes interchanged, for instance a constant torque type of Scherbius set used on a constant HP drive and given a constant HP rating for this purpose, or a constant HP type of Kramer set, given a constant torque rating for a particular drive, but this does not alter the type and will result in each case in a drive which is under-rated at one part of its speed range.

The mark of a constant HP type of set is that it has only one power connection to the line and a



E_m—Slip Voltage of Motor Secondary. (This reverses as Motor passes thru synchronism.)
E_r—Voltage required to circulate a given load current through motor secondary winding.
E_i—Voltage supplied by Auxiliaries and Impressed upon Motor Secondary.

FIG. 7—Voltage relations in secondary circuit of the Main Motor of an A. C. Adjustable Speed Set.

second machine which will operate as either generator or motor mounted on the same shaft as or coupled to the main motor. A constant torque type will have two power connections to the line and there will be no other motor connected mechanically to the principal machine.

Constant Torque Type

The necessity for the arrangement of machines used is best shown by indicating the flow of power between them. The electrical power input from the line to the main motor of a set is constant for a given load torque regardless of the speed at which it is delivered, while the mechanical output of the machine is dependent upon the speed. Thus when sufficient external resistance is inserted in the secondary of a wound rotor motor to reduce its speed 30% at full load torque, it draws 100% of rating from the line, delivers 70% of this as mechanical output to the load and 30% is dissipated in the resistor. Similarly in the case of these drives rated full load torque delivered at half speed is only 50%

of the rated motor HP and at 150% speed is 50% more than motor rating, so that neglecting efficiency, the difference must appear as electrical energy at the slip rings.

As positive energy to be disposed of in the first case and as negative energy to be supplied by the auxiliaries in the second. In other words, in order to operate the motor with these loads at these speeds, we must subtract from the slip rings, 50% of motor rating in the one case and supply 50% of motor rating in the other. The auxiliaries of a constant torque type set do just this, converting the slip energy to proper frequency and voltage and feeding it back into the line in the first case, and supplying it from the line at proper frequency and voltage in the other. The main motor alone supplies the total load torque at all speeds.

Constant HP Type

Suppose now that the drive is to deliver a constant HP at speeds both above and below synchronism. This means that at 50% speed it must deliver 200% rated motor torque, which is beyond the continuous capacity of the main motor alone. The main motor is therefore permitted to supply only its rated torque, drawing from the line full rated HP input, of which we take 50% from the slip rings as electrical energy, convert it to the proper characteristics and deliver it to an auxiliary motor which supplies the additional 100% torque.

At 150% synchronous speed the load torque required for full HP rating is only 2/3 of rated full load torque. Here the main motor delivers rated torque and takes from the line rated HP in electrical energy. Two-thirds of this torque is delivered to the load and the same machine which is used as an auxiliary motor at speeds below synchronism absorbs 1/3 of full load torque, which at 150% speed is 1/2 of rated HP, and feeds it back through the converting machine, as electrical energy to the slip rings of the main motor.

The constant HP type of adjustable speed set will then have but one power connection to the line, but will have an auxiliary machine on the same shaft as the main motor or coupled to it, and adapted for use as either a motor or generator.

Rating of Auxiliaries

The rating of the auxiliaries is determined by the amount which the speed of the main motor is regulated from synchronism and by the HP which the drive requires at the extreme speeds.

Thus the energy to be handled by the regulating machines of a constant torque type set is approximately—Shaft HP $\left(\frac{\text{Slip}}{1 \pm \text{Slip}}\right)$ using the plus sign for speeds above synchronism and the minus sign for speeds below. Their capacity is determined by the value which this calculation gives at either the highest or lowest speed, whichever is the greater.

Similarly the energy handled by the auxiliary machines of a constant HP type set is approximately —Shaft HP x % slip and their capacity is determined by the evaluation of this quantity at the top and bottom speeds of the set.

CONSTANT TORQUE TYPE SETS ON CONSTANT HP LOADS

CONSTANT HP TYPE SETS ON CONSTANT TORQUE LOADS

When a constant torque type of set is used on a load which requires constant torque only the individual machines which make it up are used at their maximum capacity and their size is a minimum. Similarly when a constant HP type set is used for a constant HP drive the maximum economy in size of main motor and auxiliaries is achieved.

But when a constant torque type set is required to deliver constant HP both auxiliary machines and main motor are larger than if the same load were carried by a set of the constant HP type and the same is true of a constant HP type set applied to a constant torque load.

This is indicated graphically in Fig. 8 Diagram of Power Flow. Case (1) simply shows that at approximately synchronous speed the auxiliaries do no work and the main motor alone delivers the total load torque in both types of set. Cases (2) and (4) illustrate constant torque ratings of 500 HP at 50% and 1500 HP at 150% synchronous speed respectively. It is shown that for the constant torque type a 1000 HP main motor and 500 HP regulating machine will deliver this rating at both top and bottom speeds and therefore a proportional one at intermediate speeds while the constant HP type will require a 1500 HP main motor and 750 HP regulating machines to take care of the rating at maximum speed and will then be operated at only 1/3 rating at minimum speed. The constant HP type set would be capable of delivering 1500 HP at the bottom speed.

Cases (3) and (5) illustrate constant HP ratings of 1000 HP at both 50% and 150% synchronous speed. In these it is shown that for a constant HP type set a 1000 HP main motor and 500 HP auxiliaries will deliver this rating at all speeds while for the constant torque type set a 2000 HP main motor and 1000 HP auxiliaries are required to deliver the rating at the bottom speed and are operated at 1/3 of rating at the top speed. This same constant torque type set would be capable of delivering 3,000 HP at the top speed.

While the foregoing indicates clearly that the greatest economy in machine size is achieved by using constant torque type sets on constant torque drives and constant HP type sets on constant HP drives, yet this is not always done because one type of drive—Scherbius—is more economically built in the constant torque type for any rating while the Kramer is usually cheaper to build in the constant HP type for any rating.

These apparently contradictory facts arise from the differences in the types of regulating machines employed and from the peculiarities of modern manufacturing methods. Thus the constant torque type Scherbius set is the cheaper because the speed of the regulating set is independent of that of the main motor and a given regulating set may serve for a drive of a certain capacity at any speed, while the regulating machine of a constant HP type must run at main motor speed and would have to be designed and built differently for the same capacity drive at different speeds. On the other hand the D.C. ma-

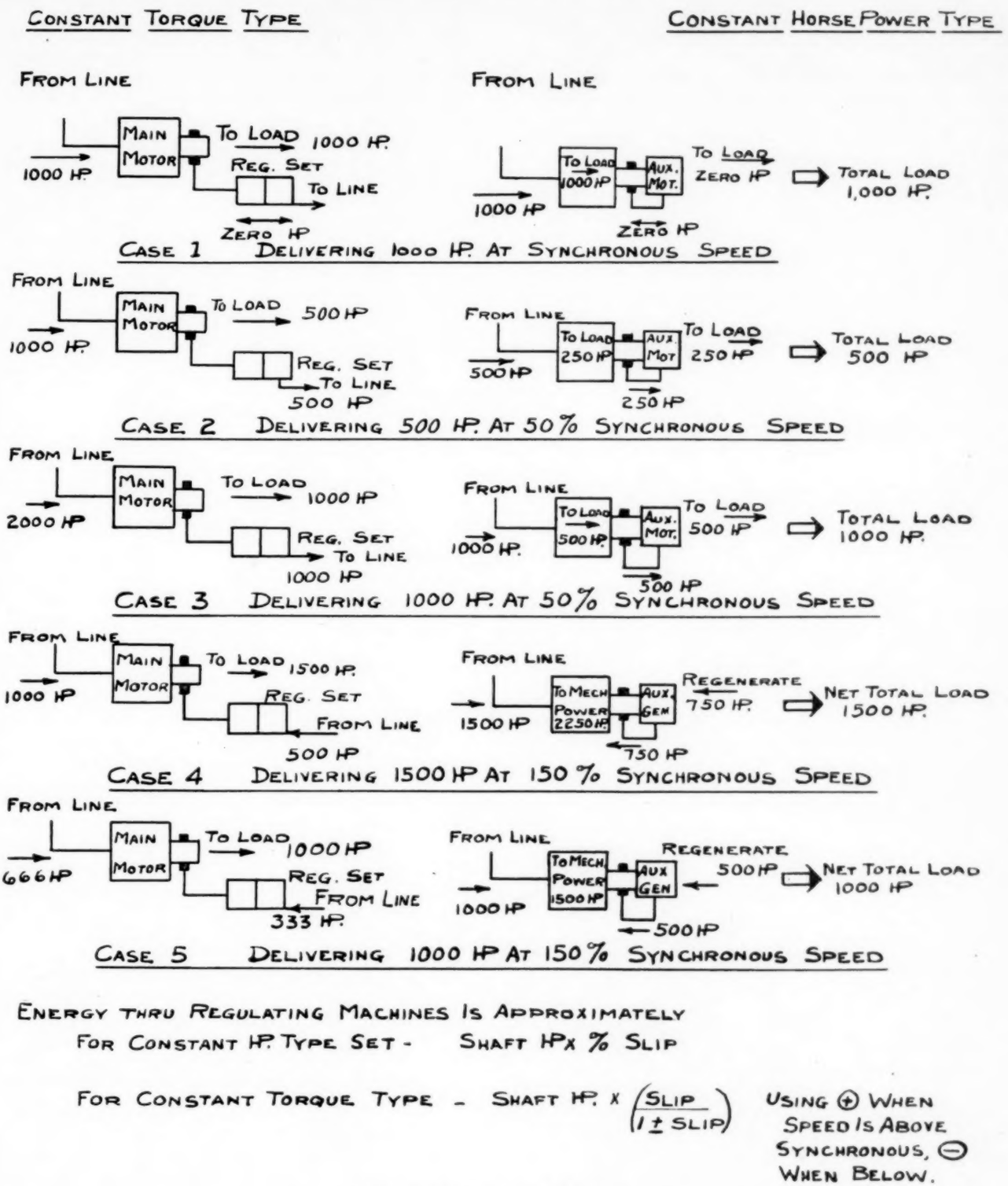

CONSTANT TORQUE TYPE
CONSTANT HORSE POWER TYPE
FROM LINE
MAIN MOTOR
1000 HP
TO LOAD 1000 HP.
REG. SET
TO LINE
ZERO HP
TO LOAD 1000 HP
AUX. MOT.
TO LOAD ZERO HP
TOTAL LOAD 1,000 HP.
CASE 1 DELIVERING 1000 HP. AT SYNCHRONOUS SPEED
500 HP
TO LOAD 250 HP
250 HP
TOTAL LOAD 500 HP
CASE 2 DELIVERING 500 HP. AT 50% SYNCHRONOUS SPEED
2000 HP
1000 HP
500 HP
CASE 3 DELIVERING 1000 HP. AT 50% SYNCHRONOUS SPEED
1500 HP.
REGENERATE 750 HP.
NET TOTAL LOAD 1500 HP.
CASE 4 DELIVERING 1500 HP AT 150% SYNCHRONOUS SPEED
666 HP
333 HP.
CASE 5 DELIVERING 1000 HP AT 150% SYNCHRONOUS SPEED
ENERGY THRU REGULATING MACHINES IS APPROXIMATELY
FOR CONSTANT HP. TYPE SET - SHAFT HP X % SLIP
FOR CONSTANT TORQUE TYPE - SHAFT HP. X (SLIP / 1 ± SLIP)
USING ⊕ WHEN SPEED IS ABOVE SYNCHRONOUS, ⊖ WHEN BELOW.

FIG. 8—Diagram of Power Flow.

chine which is coupled to the main motor of a constant HP type Kramer set is already developed in a wide range of speeds and capacities for mill and other uses and consequently the 3 machines of such a set are cheaper to build than the 4 necessary for a constant torque type Kramer set.

The principal facts to be noted in the above discussion is that the main motor must have greater capacity at synchronous speed than the rating of the set at that speed if a constant torque type set is used on a constant HP application or a constant HP type set on a constant torque application; (2)

that such a set will have additional capacity over a part of the range which may or may not be of use later; and (3) that while this difference in ratings is small for small speed ranges it increases with the range.

Power Factor Correction

The secondary current of a standard wound rotor motor is practically all power current; that is, it is in phase with the voltage which produces it and the power factor of the secondary is practically unity. The primary current has a power component corresponding to this secondary current, and also a so called "wattless" component consisting of the current required to set up the primary magnetic field, so that the resultant current taken from the power line is not at unity power factor. In each of the various types of adjustable speed sets the voltage supplied by the auxiliary machine is made to "lead" that of the main motor secondary so that the phase angle of secondary current is advanced slightly, and the small leading component thus produced compensates for the magnetizing component in the primary so that the power drawn from the line is at practically unity power factor.

By this means, the power factor of the drive is kept between 90-95% lagging and unity at all times. Usually no attempt is made to make the set take a "leading" power factor for this would require increased capacity for the same useful load capacity, and this corrective KVA is more economically obtained from M-G sets or other Synchronous machines. However one manufacturer proportions the machine so that the set has a leading power factor at light load and approximately at full load.

This article on Adjustable Speed Main Roll Drives by Mr. M. H. Morgan will be concluded in our November issue.

*Specification For 40" Reversing Blooming Mill Drive**

THIS specification covers electrical apparatus to drive a two-high reversing mill, having 40" pitch diameter rolls. The equipment is to consist of a reversing direct current roll drive motor, receiving its power from a suitable motor-generator-flywheel set and complete control equipment for same.

All auxiliary devices not distinctly specified but necessary for the successful operation of the equipment are to be furnished by the manufacturer except as follows: Customer will supply and install complete air cleaning equipment, gravity feed circulating oil system and bearing cooling water, in line with manufacturers recommendations as to such requirements.

The manufacturer shall agree to:

Pay all royalties and assume the responsibility for any patented articles used or embodied in the construction or control of this equipment, and shall assume the defense of any suit for infringement of patents brought against the purchaser by reason of the use of such articles or devices, and shall indemnify said purchaser against any damages in such suit.

Submit for approval provisions for the safe guarding of workmen, as such provisions are considered in selecting new machinery and equipment.

Furnish a competent man to superintend the installation of the equipment without cost to the purchaser.

Submit satisfactory methods of testing this apparatus, either at the factory or after installation, to check the efficiencies and ratings specified in their quotations; conduct such tests and furnish certified copies of such tests to purchaser.

*This specification is used by a large number of steel plants and is submitted for the readers of the Iron and Steel Engineer as a guide in preparing specifications of this nature.

Quotations are to cover the following points:

Time required for delivery.
Price—F. O. B. Destination.

Data as requested on data sheets which are a part of this specification.

Outline dimension drawings of machines and auxiliaries.

Complete description of control equipment.

ROLL MOTOR—SPECIFICATIONS

Reversing direct current motor— ——— volts per armature, (shunt or compound) wound main fields, separately excited, with interpole and compensating field windings. Both bearings are to be water cooled and bearing pedestal opposite mill end bearing shall be insulated from the frame.

Speed—Base speed of — RPM with full field excitation and full voltage impressed on armature. Speeds above base speed, up to a maximum of —— RPM to be obtained by field weakening.

Rating— —— HP continuous, without exceeding a 50°C rise above surrounding air, at — RPM, with full field excitation, when supplied with artificial ventilation.

Normal Continuous Torque— ——— lbs. ft.

Normal Maximum Torque—225 per cent of normal continuous torque— ——— lbs. ft. The current corresponding to ——— lbs. ft. torque with full field excitation on motor is to be the permissible current limit relay setting.

Maximum Emergency Torque—300 per cent of normal continuous torque— ——— lbs. ft. The current corresponding to ——— lbs. ft. torque with full field excitation on the motor is to be the permissible circuit breaker setting.

The motor shall be capable of delivering its continuous rated horsepower of ——, at speeds between —— and —— RPM, with a temperature rise not exceeding 50°C, it being understood that the torque will vary inversely with the speed when operating above the full field speed of — RPM.

The motor shall be capable of commutating currents corresponding to current limit relay and circuit breaker settings at any speed between zero and ——RPM, without injurious sparking at the commutator.

FLYWHEEL MOTOR—GENERATOR SET—SPECIFICATIONS

Generators—The generators shall have a combined continuous capacity of —— K.W. without exceeding a 50°C rise above surrounding air. They shall be capable of meeting all of the requirements of the roll motor as outlined above without injurious sparking or excessive wear on the commutators.

Induction Motor—The induction motor shall be of the wound rotor type, and have a continuous rating of —— HP without exceeding a 50°C temperature rise above surrounding air and shall operate on a —— volt, —— cycle, — phase system.

Flywheel—The flywheel shall have stored energy to the amount of ——— HP seconds when operating at the synchronous speed of the induction motor.

Bearings—All bearings are to be water cooled, and all bearing pedestals insulated from the frame of the machines.

AUXILIARY EQUIPMENT

Exciter—A suitable motor generator set shall be furnished, driven by a —— volt, — phase, —— cycle induction motor, with a direct current generator suitable for power supply for field excitation, complete with remotely controlled starting equipment.

Transformers—3— —— K.W. —— to —— volt single phase, —— cycle transformers shall be furnished to supply power for the induction motor of the exciter set.

Slip Regulator—A slip regulator shall be furnished for starting and operating the induction motor of the flywheel motor generator set. This regulator shall be capable of handling the power induced in the secondary of the induction motor when reverse power is applied for quick stopping of the flywheel motor-generator set.

Oil Circuit Breakers

Two oil circuit breakers, for forward and reverse operation of the induction motor, shall be furnished, the minimum acceptable ratings of which are—— ampere continuous capacity— —— volt insulation, ——— ampere rupturing capacity at —— volts. One oil circuit breaker of same rupturing capacity shall be furnished for use with the auxiliary transformers. These circuit breakers are to be solenoid operated from a —— volt source of power on the closing coil. The trip coils are to be operated from an — volt battery, which shall be furnished complete with charging panel by manufacturer.

D.C. Air Circuit Breaker—One D.C. overload circuit breaker shall be furnished to open the circuit between the roll motor and generators. This breaker is to be electrically operated and provided with auxiliary contacts to energize position indicating lights on switchboard and such other auxiliary equipment as may be required by the scheme of control employed. The capacity of this breaker shall be —— amperes continuously, without exceeding a 30°C temperature rise above surrounding air. Mounted on the same panel and connected in series with the breaker shall be a knife switch of the same capacity.

CONTROL EQUIPMENT

A suitable switchboard shall be furnished, mounting the meters, switch controls and other devices as outlined below.

Induction Motor Control

Forward and reverse switch operating controls with red and green lights.
2—Overload Relays—1 under voltage Relay.
1—A.C. Voltmeter.
1—A.C. Ammeter.
1—W.H. Meter.
1———— Graphic Wattmeter, scale 0-10,000, with hour and minute feeds.

Auxiliary Transformer Control

1—Switch operating control with red and green indicating lights.
2—Overload Relays—1 under voltage Relay.
1—A.C. Ammeter—5 ampere—100 ampere scale.
1—A.C. Watthour Meter.

Exciter Control—Induction Motor

1—Switch operating control with red and green indicating lights, for starting and stopping induction motor on exciter set.
1—A.C. Ammeter—5 ampere, suitable scale.

All current transformers and potential transformers, with 2 ampere fuses, necessary for the operation of the above meters, relays, etc., shall be furnished.

Exciter Control—D.C. Generator

1—D.P. S.T. back connected Knife Switch for main exciter generator circuit.
1—D.C. Ammeter.
1—D.C. Voltmeter.
1—Hand operated field rheostat for generator field.

Roll Motor and Generator Control

1—Switch operating control with red and green indicating lamps for main D.C. breaker.
1—D.C. Voltmeter—1,000—0—1,000 volt scale indicating.
1—D.C. Ammeter—15,000—0—15,000 scale indicating.
1—D.C. Ammeter—for generator fields—indicating.
1—D.C. Ammeter—for roll motor fields—indicating.
Field ammeters to have range sufficient to show peaks encountered during field forcing.
1—Twin Graphic ———— Meter, recording D.C. Kilowatts, scale 0—10,000, and D.C. amperes, scale 15,000—0—15,000, with hour and minute feeds.

1—Graphic Meter, recording RPM on roll motor, scale—150—0—150 RPM with hour and minute feeds.
1—Speed indicating Meter—scale 0 to synchronous speed of induction motor on flywheel set.

For Rollers Pulpit

1—D.C. Ammeter—scale 15,000—0—15,000 indicating.
1—D.C. Voltmeter—1000—0—1000.
1—Speed indicating Meter—scale 0 to synchronous speed of induction motor on flywheel set.
1—Speed indicating Meter for roll drive motor. Red and Green indicating lights, showing position of main D.C. circuit breaker, and main oil circuit breaker.
1—Safety Switch, with locking device, to prevent closing of main D.C. Breaker.

All shunts, fuses, etc., necessary for the operation of the above described direct current meters, relays, etc., shall be furnished by the manufacturer.

Field Control—Roll Motor and Generators

A suitable field control panel shall be furnished, complete with resistors and master switch for the control of field excitation on the roll motor and generators. The minimum number of control points shall be—two points below normal voltage, with full motor field, one point at normal voltage with full motor field, and three points with normal voltage and weakened motor field. All contactors shall be of sufficient capacity to carry the field currents encountered during operation, including the peaks obtained during field forcing, without injurious heating. The master switch shall be of the foot operated type, with an alternative on hand operated type if the manufacturer so desires.

Auxiliary Control Panels

A panel shall be provided, with 1—3 P.—D.T. —— Amp. Knife Switch to allow the operation of the exciter and air washer motors from the plant —— volt system if —— volt transformers are not available. Also 1—2 P.—D.T. switch of suitable capacity to allow the use of ———— volt D.C. plant system for control and field excitation if exciter power is not available.

A panel shall be provided for field circuit breakers if field breakers are employed, and are not mechanically operated in connection with the main D.C. Breaker.

Control circuits shall be arranged so that the oil circuit breakers will operate from plant —— volt D.C. power. All other control circuits will operate from exciter D.C. power.

Complete drawings of switchboard and control panels shall be submitted for approval before construction is started on same.

All control devices on switchboard shall be of one type to give a symmetrical appearance to the switchboards. Meters are to have white dials with black figures.

ROLL MOTOR DATA

1. Weights—Total Armature Complete
   Shaft Field Frame Pedestals and Base
2. Dimensions—Overall Length Width
   Height above Base Shaft Diameter in Spider
   Shaft diameter in Bearings
   Mill end Bearing Rear Bearing
3. Armature Diameter Length of Stackings
   WR^2 Material in Spider
   Single or double unit Volts per Armature
   Air Gap single radial
4. Commutator diameter Active length
   Number of Bars Thickness of Bar
   Volts per Bar Thickness of Mica
   Weight of Copper Current Density
5. Brushes—Size Number per Arm
   Current density Grade
   Amperes per brush arm Material in brushholders
6. Poles—number per armature Laminated
   Interpoles—laminated
7. Description of interpole bracing
   Description of insulation of armature and field coils
   Description of windings and cross connections
   Description of pedestal holding down bolts
   Description of thrust bearing construction
8. Material in base Pedestals
   Magnet frames Armature spider
   Commutator spider
   Shaft approximate-analysis
9. Bearings—water cooled Ring oiled
   Arranged for circulating oil connections
   Bearing pressures, based on projected area of bottom one-third of bearing
   Babbitt analysis
   Capacity of wells Oil level gauges
   Thermalarms furnished
10. Efficiencies ½ load ¾ load full load
11. Amount of Air required to deliver rated capacity
12. Time required to reverse from — to 0 to — RPM and from — to 0 to — RPM
13. Torque required to accelerate armature — RPM per second.

MOTOR GENERATOR—FLYWHEEL SET DATA

1. Weights—Total Base Pedestals
2. Dimensions overall length Width
   Height above base (flywheel)

Generator Data

1. Weights—Total Armature complete
   Shaft Field Frame Pedestals and Base
2. Dimensions—Overall Length Width
   Height above Base Shaft Diameter in Spider
   Shaft diameter in Bearings
   Mill end Bearing Rear Bearing
3. Armature Diameter Length of Stackings
   WR^2 Material in Spider
   Single or double unit Volts per Armature
   Air Gap single radial
4. Commutator diameter Active length
   Number of Bars Thickness of Bar
   Volts per Bar Thickness of Mica
   Weight of Copper Current Density
5. Brushes—Size Number per Arm
   Current density Grade
   Amperes per brush arm Material in brushholders

6. Poles—number per armature Laminated
   Interpoles—laminated
7. Description of interpole bracing
   Description of insulation of armature and field coils
   Description of windings and cross connections
   Description of pedestal holding down bolts
   Description of thrust bearing construction
8. Material in base Pedestals
   Magnet frames Armature spider
   Commutator spider
   Shaft approximate—analysis
9. Bearings—water cooled Ring oiled
   Arranged for circulating oil connections
   Bearing pressures, based on projected area of bottom one-third of bearing
   Babbitt analysis
   Capacity of wells Oil level gauges
   Thermalarms furnished
10. Efficiencies ½ load ¾ load Full load
11. Minimum speed at which generators will deliver full voltage

Induction Motor

1. Weight—Total Stator Rotor complete
   Rotor less shaft
2. Dimensions Diameter of rotor Length rotor Stackings
   Length stator Stackings Air Gap
   Diameter Shaft in Stackings In bearings
   Air Gap
3. Ratings—HP Continuous—50°C rise KVA
   Synchronous Speed Full load speed
   Amperes per terminal primary
   Maximum running torque
   Rotor current full load
   Volts between rings—at stand still
   Volts between rings—when plugged
   Efficiency—½ load ¾ load Full load
   Power factor—½ load ¾ load Full load
4. Bearings Dimensions Arranged for circulating oil
   Oil level gauges Ring oiled Water cooled
   Bearing pressure
   Thermalarms furnished
5. Material used in rotor spider Bearing pedestals
6. Description of insulation Voltage test
7. Description of coil bracing

Flywheel—Weight Diameter Face
Stored energy at synchronous speed
Stored energy of complete rotating element of flywheel-motor generator set a synchronous speed
Shaft dimensions
Bearing dimensions Water cooled
Ring oiled Arranged for circulating oil
Oil level gauges Thermalarms
Enclosure furnished
Description of construction of wheel
Bearing pressure based on projected area of bottom one-third of bearing
Rotating speed in bearings
Description of method used to prevent oil getting into machines from bearings.

Micarta Non-Metallic Gears in the Steel Mill Industry

By T. C. ROANTREE*

WHEN the subject of the steel mill is brought to the attention of the layman, one of the mental pictures that presents itself is that of high temperatures caused by the furnaces and its product of molten metal. Another picture likely to appear is that of the great, almost ponderous machines, necessary to carry on to completion that particular metal product upon which the furnace had performed but the initial step in the processing.

Throughout both these pictures, and as a general accompaniment to the thought, there is present a sense of more or less turmoil amid noises and concussions that are shocks to the unaccustomed ear and nerve centers.

There was a time when the proposal of using a non-metallic gear material in an atmosphere of this nature was believed by the mill superintendents as not being worthy of the slightest consideration, for, realizing the general heavy nature of the machine duties, they naturally thought that a material having a fabric base could not possibly be utilized as a substitute for metal gears in a plant of that kind.

However, the improvements made over the period of the last ten years in the perfection of Micarta gearing material has brought about a complete change in the attitude of men in the steel mill industry toward this type of material. It is now being adopted in many mill applications as the standard form of gear drive, for, experimental substitutions for metal gears have proven this material to have far greater strength and wearing properties than had been expected by the most optimistic.

Naturally, there are many noises in the steel industry that cannot be eliminated nor, in some cases, even modified, and these are probably considered as necessary evils. Nevertheless, such noises

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as can be removed or lessened, betters the working conditions for the employees just that much, for there have been so many authorized investigations and scientific studies made in verification of that claim, that there can remain no doubt of the betterment to the nerves and general health conditions of the workman through the absence of noises and vibrations during their working hours.

In addition to the advantages gained of a humanitarian nature the mechanical gains are also prominent. It is a known fact that vibrations are not only a factor in the noise element of any machine, but that the machine having the least vibration, other conditions being equal, will give the most accurate service and have the longest life.

It is evident that a double role is played by this class of gearing in its use as a substitute for metal gears and that is the reason the more progressive supervisors in the mills are constantly seeking additional applications upon which the advantages of this material can be utilized.

In the machine shop, where the barrel rolls are cut preparatory to their use in the mill, the non-metallic material is found as a pinion on the motor driving the lathe upon which this work is performed. The motor drives for these lathes vary in horsepower capacity according to the size of the work the lathe performs. Non-metallic applications of a general type on this work are represented by the following two specific examples: A non-metallic pinion of a 3 diametral pitch, 40 teeth, 7 inch face width is used on a 50 horsepower motor running from 400 to 1200 revolutions per minute and on another motor of the same capacity and speed the non-metallic pinion is of 2½ diametral pitch, 30 teeth and 5″ face width.

It is worthy of note that the non-metallic pinions in the above applications have a carrying capacity of from 40 per cent to 50 per cent greater than the horsepower rating of the motors in addition to the factor of safety of 3 that is incorporated in the formula used for the computations.

In this type of application, there is no impact load thrown on the gear teeth as the lathe tool takes but a slight amount of material with one cut and is fed in gradually, but that comparatively ideal condition cannot be said to be present in the trimming shears that are used in this industry.

On a trimming shear, there is a sudden requirement of the power necessary to force the knife edge of the shear blade through several thicknesses of plate stock or a piece of bar stock and then the load suddenly drops to practically nothing or just sufficient to lift the shearing blade to a position to repeat the operation. This machine, therefore, imposes a sudden impact shock on the teeth of the non-metallic gear that happens to be in mesh at the time the shear blade first comes in contact with the material to be cut.

The use of the non-metallic pinion on this type of machine has been found to eliminate a considerable amount of expense that had previously been experienced in the replacement of the metal pinions due to breakage when some unusual condition would arise. Further, the non-metallic pinion preserves the tooth surfaces of the large mating gear, which would eventually become so mutilated from the contact with a metal pinion that it also would have to be replaced at a comparatively very great cost in money and considerable loss in production.

An example of an application of this nature, where the non-metallic pinion provides a quieter job, absorbs the impact and vibration shocks and lessens the expense of the maintenance of the gear train, is the following: On a motor rated at 150 horsepower but run normally at half that load, a non-metallic pinion of 2¼ diametral pitch, 18 teeth and 7″ face width running from 575 to 860 revolutions per minute has performed satisfactorily for a long period where formerly the metal pinion had frequently failed.

Another interesting application of a somewhat similar nature, so far as shocks are concerned, is that of a cold rolling copper mill, when accidentally an exceptionally thick section of the material is encountered by the rolls.

On this particular job, there was a cast iron coupling used at a certain inaccessible part of the machine and upon such times as a kink in the material or an exceptionally thick section would be grasped by the sizing rolls, this coupling of 1½″ stock, 12″ in diameter and 14″ long would invariably break, causing a shut down of the mill for a couple of days until replacement could be made.

With the idea of effecting a breakage at a more accessible point with subsequent saving of time, labor and production, the hardened steel driving pinion was removed and a non-metallic pinion substituted. This idea based on the same theory as a fuse in an electric circuit seemed to be the practical solution, until the next strain was exerted, when the coupling again broke, while the non-metallic material, through its possession of the factor of resiliency, remained intact.

The substitution of a hardened steel for the coupling material finally concentrated the trouble at the point desired, but it was noted that trouble arose far less frequently than formerly. The cost of replacing the Micarta pinion was less than 5 per cent of the expense incurred in the coupling failures and production was delayed less than two hours instead of a two day (and night) shutdown.

Although the resiliency of Micarta is demonstrated in the above types of machines through the effects of great impact loads it perhaps shows this quality just as impressively, for, as a driving pinion on a corrugating machine the non-metallic material has proven its practicability over the metal pinion to a marked degree. One mill in which this type of work is prominent, has found that the non-metallic gear is as great a success as the metal gear was a failure.

A somewhat similar application is that of the machine used for forming, punching and sizing steel barrel hoops. In this machine the Micarta pinion is subjected to repeated impact blows produced by the hole-punching and trimming actions of the mechanism of this type of machine. Here, again, the non-metallic has been adopted because of its far greater life than the usual metal gear.

Due to the variety of the work in a steel mill, Micarta has proven its adaptability to many applications that require a great range of properties in order to have it function satisfactorily. The facility

of resisting the effects of plating compounds and mild acid solutions has made it a very desirable gearing material for use on continuous galvanizers.

In this application, the metal gears are soon found to be accumulating additional surface. This condition brings about a gradual spreading of the centers and exerts a tremendous strain on the bearings due to the simultaneous enlarging of the gear tooth with the lessening of the space into which it should mesh. The dire results of this condition can readily be appreciated and the substitution of non-metallic material for the gear most effected will reduce this condition at least sixty per cent.

On the "scrubbers," there is frequently a cleaning fluid used that has a detrimental effect on the metal gears to the extent that they become pitted with the splash of the liquid and consequently wear rapidly as the back lash develops. Micarta pinions have proven very proficient substitutes for metal, as such solutions have no effect whatever on the tooth surface and subsequently much greater life is obtained in the gear train.

In addition to the wearing of the metal gear surfaces through contact with acid solutions, in the steel industry, there is also a condition wherein the surfaces are sometimes even more rapidly worn by virtue of abrasives. This condition is found in their "Plate Cleaners," and although the ability of Micarta to withstand this influence is possibly better demonstrated in their satisfactory performances on sand mixers and coal and coke conveyors, the presence of "peanut bran" as the cleansing agent used on these machines makes their application here very favorable.

This abrasive rapidly wears the surfaces of the metal gears particularly at the pitch line with the result that "flats" are developed on the teeth and an excessive back-lash set up that increases the impact and produces very rapid wear and numerous strains on the bearings with every revolution of the gears. Micarta resists this action to a very great degree and through the subsequent reduction of the vibratory action provides a quieter operating machine, and greater life to the bearings and the machine itself. The reduction in the cost maintenance and in the depreciation is very evident.

In the wire mills, many applications for Micarta have been found prominent among which are the pinions on the "sizer," "galvanizer," and "twister" or "strander." The former job is similar to the cold rolling copper mill application mentioned before; the "galvanizer" gives the non-metallic gear an opportunity to show its qualities of resistivity to such surfacing influences and the term really explains the operation; the "twister" or "strander" has a double application for Micarta, for, on this machine in which several strands of wire are twisted into a wire of the desired larger dimension, Micarta is used as "rollers" upon which the twister-cylinder revolves.

The use of Micarta in the latter case does an exceptionally good job of quieting, for the rolling of the metal cylinder on cast iron wheels or pulleys was a source of tremendous noise and, of course, the metal to metal contact of that type gave an excessive vibratory action which was also eliminated by the use of a non-metallic roller.

The effect of moisture is also negligible on Micarta gears and this is fairly well demonstrated on their "oilers" where the non-metallic gearing material has performed successfully in the steel industry. In fact, there are numerous applications in various mills that are peculiar to that particular plant and which are not mentioned here, for it is thought that the great variety of applications mentioned above, with their individual demand for the possession of some specific property in Micarta in order that it will provide the improvement desired, should show conclusively that the non-metallic material for use as gears in the steel mill is providing a long needed relief to the noise and machine maintenance costs in this gigantic industry.

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*The Correction of Unsafe Practices in Foundries**

By NELSON H. KYSER†

SEVERAL hundred years ago, the idea was conceived that castings could be made from molten metal. At that time, no doubt, the process was very crude, and development up until now has been next to phenomenal, as the modern methods and devices for handling molten metal have been steadily improving each year. Even in the light of this remarkable progress, I am very firmly convinced that there is yet a world of room for further improvement.

In years past industry was conducted on what might be termed a "miniature basis." Our huge manufacturing monuments of today were mere blacksmith shops of one or two rooms. The foundry proudly boasted of a cupola of a ton capacity per day and the personnel consisted of a handful of men who were all very closely associated with their employer. Every one of these men was working with, rather than for, his superior. The amount of molten metal handled was small and the hazard negligible. Today with our foundries having a capacity of hundreds of tons per day and employing thousands, we are faced with the problem of correcting those practices which make for anything unsafe. The ultimate we are striving for is to obtain that same spirit, that same working together, which we had in years past in the small shop.

Several years ago the corporation which I represent constructed a very modern foundry which occupies 13½ acres of floor space and at normal

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times employs about 1,300 men and women. When we inaugurated our safety organization we, like all other companies, had our troubles in getting employees educated along lines of working safely and protecting themselves. However, we have made a very wonderful showing, due to the fact that everyone from the production manager on down to the floor sweeper is vitally interested.

This, I think, is the keynote to foundry safety. We must educate every soul connected with foundry work to think, act and live safety. The individual who does not think of his own personal safety or of the injury to others which might result from his negligence is criminal in intent and is the worst hazard a foundry can have. Quite often such a man exists simply because he has never been educated to safe practices.

The foundry superintendent, the foremen, the gang bosses, all hold their positions because they have a superior knowledge of foundry work and, secondly, because they are executives in some degree. It is with these men that the safety school must start. These men must get the safety habit and believe in it. They in turn must pass it on to their men and in the case of a wayward one give him a little personal contact to show how much better off he and his fellow workers will be if they are all working safely. Men should be picked for the particular job for which they are most fitted and in case of an unsafe move should be shown where they are at fault. However, a man who is continually working unsafely is a hazard to himself and his fellow workers and should be discharged for his disobedience and unsafe practice.

The actual education of the men will vary according to the specific problems of each individual foundry, but there are a few fundamentals that will apply to foundries in general.

Every man must be taught to be a good housekeeper, as a clean, orderly shop means careful workmen and greatly reflects on the quality of the product. If aisles and passageways are blocked or are strewn with foreign matter the possibility of spilling a ladle filled with molten metal is greatly increased. If flasks are piled so that they may topple over, the hazard of crushing or badly lacerating a fellow workman is present. Many other instances might be cited where a poor housekeeper was the cause of an accident, but this is really a problem for each individual foundry to work out. If each foundry superintendent would call his foremen together and outline a program of getting clean and keeping clean, good housekeeping would no longer be a task and would become a habit and the unsafe practice of poor housekeeping would no longer exist.

There is always a safe way and a dangerous way to do a job. We may show a man the safe way to do the job by calling his attention to the danger of the different operations, but it would be folly to set forth a hard and fast set of rules for him to follow. In my judgment, it would be better to allow the man himself to develop the safest method of doing the job without injury to himself because of the vast difference in human element. It would be ridiculous to expect men of different status and temperament to work with identical movements. The employee should be cautioned against using a rusty skimmer or rod when skimming or stirring molten iron and should be told of the danger which results. The pouring of molten metal into moist ladles should also come in for its share of caution, as should the watching of a mould up through the risers without the necessary goggles. There are many other things in this connection which are dangerous and where the new man is very liable to encounter sorrow. Here again is where the executive in charge functions as a teacher.

Proper clothing must come in for its share of consideration in the correction of unsafe practice in foundries. We insist that all men engaged in the handling and pouring of molten metal in our foundry must have good, solid Congress shoes without the slightest defects; either asbestos trousers or slow combustion leggings; wool shirts preferably and regulation safety goggles. Without these articles they are not given any metal from the pouroff man who has charge of the large distributing ladle. This rule is enforced 100 per cent and the results are gratifying, as very seldom is a man denied metal due to his being unsafely clothed.

The time to teach the employee that burns and injuries caused from unsafe clothing result in intense pain; loss of time and money, both to himself and employer; and often permanent injury, is before he has to personally undergo these tortures. It is much easier to enforce rules relative to proper clothing if each workman realizes that he is not being made to wear certain articles because it is so much red tape, but as a safeguard to himself. We have attempted to teach safety with kind words, and this always is our first method of attack, but in some instances we must resort to what is called "hard boiled" procedure, as it is strongly human for some individuals to disobey rules which have been inaugurated for their own welfare, and in rare cases we have resorted to immediate discharge of an old offender.

Thus far we have dealt only with personal education as a means of correction of unsafe foundry practice. Now we must turn our attention to the hazards which are directly due to the foundry layout. The more mechanical devices we are able to install the less will be the possibility of accidents. In our foundry we have attempted to do as much work by mechanical means as seems practical. Although we are not as yet 100 per cent, we hope in the near future to install mechanical means of doing certain jobs that further remove the employees from the danger zone.

Let us start with the raw pig and follow through until the castings are ready for machining. The opportunity first presents itself to do the work mechanically in the handling of raw stock. Magnetic cranes can be brought into use for the pig and scrap, while hopper bottom bins make a safer and easier way to handle the non-metallics. All the ingredients of the charge may be loaded into small cars, weighed and transferred to the charging floor untouched by the human hand. This practice will eliminate crushing injuries and also the possibility of hernia, which is frequently caused by the strain of overlifting.

After the charge is on the charging floor it should be mechanically dumped into the cupola. This

method will avoid hand shoveling of the charge, where a man is apt to slip and fall into the mouth of that raging hell. Serious thought should also be given to proper ventilation, as the gases on the charging floor are very poisonous. In cases where the ventilation is poor or the ventilating system temporarily inoperative, the workman should be furnished with suitable respirators.

In the pouring of molten metal comes one of the most important applications of mechanical means and also one that is used the least. When a full ladle of molten metal has to travel hundreds of feet over the heads of a great many workmen the hazard of dropping and slopping over may result in serious burns. If instead of this dangerous practice of transferring the molten metal a great distance the conveyor system for carrying the moulds could be installed, one of our greatest foundry problems would be solved. The moulds could be placed on conveyors and transferred to a point 25, or not over 50, feet from the cupola and poured. This would bring but relatively few men into the danger zone.

The installation of a conveyor system of this type would require a sizable expenditure, which at the very outset might look somewhat unreasonable, but when we enumerate the benefits derived from its installation we can easily see where it would correct one of the most unsafe foundry practices. The peace of mind of all concerned would be without price; the inspection of long monorail systems would be eliminated; the danger of slop over would be cut to a minimum; and the use of hand ladles, with their many evils, would be history.

After the moulds are poured they continue on the conveyor to the shakeout, where extreme care must be exercised whether done mechanically or by hand.

The shipping and grinding departments should be in a separate room from the rest of the foundry. This room should be well lighted and ventilated. All workmen should wear goggles and hard toed shoes to avoid eye and foot injuries. The various tools should be frequently inspected for their suitability and condition. The use of chisels with mushroom tops is very dangerous and should always be avoided. The chipping room should be large enough to allow considerable distance between each chipper, as flying chips often are responsible for serious injuries.

In closing, let us summarize the high spots in the correction of unsafe practice in foundries. First of all, the safety engineer can only be the watch dog and must have the co-operation of every foundry employee. To obtain this co-operation every man must be educated in the school of safety to be a good housekeeper, a safe worker, to dress properly and, where the occasion demands, wear his goggles or respirator. Secondly, the management itself must give serious thought to the safest layout possible in order that it may make use of all possible mechanical means, thereby removing the employee from unnecessary and avoidable dangers.

Our ultimate aim must be to safeguard our foundries so completely that when day is done and the rank and file are homeward bound that each and every wife and mother may anticipate, without the slightest trace of fear, the greeting of their loved ones, whole and unmaimed; that every man, robust and strong, healthy and of a light heart, may caress his own little ones as the sand-man comes, knowing that on the morrow they will not be sorrowing his untimely injury or death.

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Association of Iron and Steel Electrical Engineers

A. I. & S. E. E. JUNIOR DIVISION

(Devoted to practical problems of electrical department employees in the Iron and Steel Industry)

Standard Testing Direct Current Generators and Direct Current Motors

In presenting this information taken from General Electric Company's testing manual, the Association of Iron and Steel Electrical Engineers feel that the man in the field may find many valuable suggestions that will aid him in his future problems in maintenance.

It is recommended that the Junior Member study this article carefully with the view of increasing his knowledge and efficiency in handling, operating and maintaining Direct Current Generators and Motors.

Articles of this character and description will appear regularly in the columns of the Junior Membership Section of the Iron and Steel Engineer. *Editor.*

DIRECT-CURRENT GENERATORS

The tests on direct-current generators may be divided into the folloiwng groups:

Static Tests.
Short Commercial Tests.
Short Commercial Tests and Adjustments.
Complete Tests.

STATIC TESTS

A static test on a direct-current generator includes the cold resistance measurement, potential drop, polarity of all fields, air gap measurement, and high-potential tests.

SHORT COMMERCIAL TESTS

A short commercial test on a direct-current generator includes the cold resistance measurement, potential drop, polarity of all fields, location of neutral, plot of a saturation curve, "running light," speed limit and end play setting, bearing temperatures, and high potential tests.

Location of Neutral

After cold resistance and polarity tests have been taken, the brushes should be set on mechanical neutral. Referring to Fig. 1, one armature coil contained in a pair of slots in the armature core and the corresponding commutator segments are marked for the convenience of the Testing Department. The coils are marked with red paint, and the ends of the corresponding commutator bars are stamped with the letters T and B. The letter T designates a coil which lies in the top part of a slot and the letter B designates a coil lying in the bottom of the slot. In a machine with a full pitch winding, the two red marked armature inductors (A) forming a coil, will come one pole pitch apart. When setting the brushes, these conductors should be placed directly under the centers of the commutating poles as shown, and the brushes shifted until the center of the brush rests on the center line of the commutator segments corresponding. On a fractional pitch winding, the two red conductors will not span a full pole pitch, but they should be so located that they are equidistant from the center of their respective poles, as shown by the dotted lines B-B, and the brushes set as above. If there is more than one coil per slot, there will be a corresponding number of commutator segments stamped T and B, but the middle one should be used.

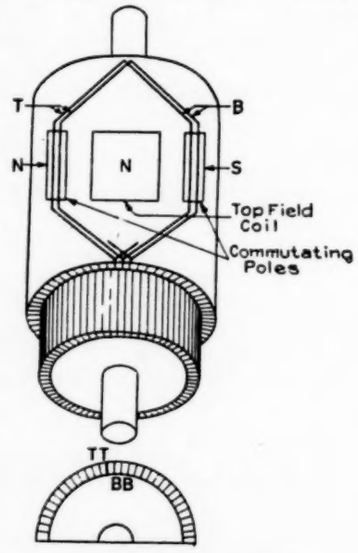

FIG. 1—Diagram showing marking of armature and commutator for locating mechanical neutral.

Saturation Curve

The direct-current generator should be run at normal rated speed. Before starting, the direct-current brushes should be sanded. On machines that are to be shipped "set up," all of the brushes should be sanded, and on machines that are to be shipped "knocked down," only sufficient brushes to carry the

running light current should be sanded. The saturation curves should be taken as follows:

Saturation

In order to ascertain the characteristics of the magnetic circuit, a test known as saturation is made. The characteristic curve may be obtained by either of the following methods: Generator saturation, or motor saturation.

Generator Saturation

To obtain a saturation curve by this method, the machine is driven at normal speed as a generator. The brushes of direct-current machines should always be set on neutral, and the machine run at its normal rated speed.

In taking the saturation curve on polyphase alternating generators, a reading of the voltage across each phase must be taken at normal field current, to see if all phases are properly balanced. If they do not balance, they must be made to do so. With synchronous converters, careful readings must be taken of direct voltage, as well as the alternating voltage, between all phases with the field excitation giving normal voltage. The phase voltage must also be closely balanced.

The usual method of taking the generator saturation curve is to hold the speed constant, and then increase the field current step by step until full field excitation voltage has been reached, taking simultaneous readings at each step of armature voltage, field voltage, and field amperage. **About twelve points are sufficient. Four readings should be taken from zero field to 90 per cent normal rated voltage of the machine. Five points should be taken between 90 per cent and 100 per cent normal rated voltage, taking one of the points at the normal rated voltage of the machine. Three points should be taken between 110 per cent normal rated voltage to full field on the machine.**

After reaching the maximum value of the field current, without opening the field, reduce the current gradually in four or five steps, and again take readings to determine the value of residual magnetism at various points along the curve. Special care must be taken to insure accurate readings at and above normal voltage, for in alternating-current generators this is the portion of the curve used for calculating the regulation load.

On separately excited, high-voltage, direct-current generators, the saturation curve should be carried only to 25 per cent above the normal rated voltage.

Motor Saturation

When it is inconvenient or impossible to drive the machine as a generator, a motor saturation curve may be made. For this case, the machine is operated as a free running motor. The driving power must be furnished from a variable-voltage circuit. A certain voltage is impressed upon the armature and the motor field increased or decreased, in the case of direct-current machines, to give normal speed, and a record made of armature voltage, armature amperage, field amperage, field voltage, and speed. The starting voltage should be at least 50 per cent lower than the normal rated voltage of the apparatus. The applied voltage of the armature should be increased by steps to 25 per cent above normal value, and the field increased correspondingly to keep the speed constant, the same readings being recorded at the various steps as before. Readings should also be taken at three or four points as the impressed voltage and field current are lowered to approximately the values at the beginning of the test.

Care must be taken in testing direct-current apparatus, because unstable electrical conditions may develop, and excessive speeds result. The circuit breaker, in the armature circuit of the motor driving the machine, must be accessible to the tester reading the speed.

On alternating-current appartus, the machine is run as a motor and the impressed voltage varied as already described. The speed is independent of the motor field in this case and instead of regulating the motor field for speed, it should be regulated to give minimum input current at each voltage. Readings should be taken of each voltage impressed, armature amperage, field amperage, and field voltage. With induction motors, it is only necessary to impress variable voltages at constant frequency and record readings of impressed armature voltage, armature amperage, and speed.

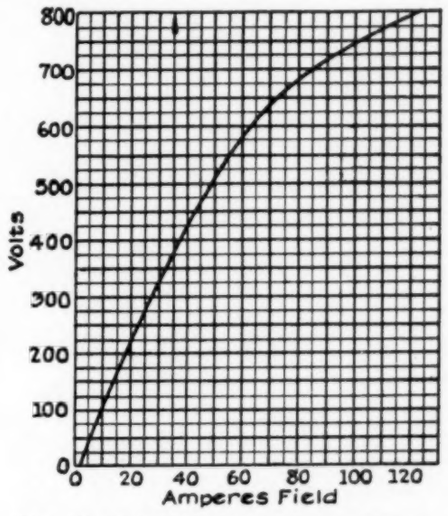

FIG. 1A—Saturation curve on a 500 kv., 600 volt, 20 pole, 360 rpm., 3 phase, 60 cycle, alternating current generator.

A curve should be plotted, using armature voltage as ordinates and field amperage as abscissae. Fig. 1A shows a saturation curve.

If the machine has been assembled and connected correctly, it should build up when the shunt field switch is closed and all resistance is cut out. To make sure that all of the resistance has been cut out of the field circuit, the field boxes may be short circuited by a short piece of wire temporarily held against the terminals. If it does not build up, the connections should again be checked with the wiring diagram, and the polarity and resistance of the shunt field, and the different specifications rechecked. If these prove to be correct, the field switch should be opened and the residual armature voltage noted. If, upon closing the switch, this decreases or drops to zero, it shows that the machine is not wired properly and that the current tends to flow in the wrong direction through the field. This condition should be referred to the office, for the only way to remedy it

is to change the connections. If, however, the residual armature voltage does not diminish when a field switch is closed, it may be necessary to flash the field by sending a current from some external source through it in the proper direction.

The building up of a series generator is a more complicated operation. The load increases with the voltage. Great care must be taken in obtaining the correct external resistance, to prevent the voltage from increasing too rapidly. As it is practically impossible to decrease the external resistance enough (by lowering the blade in the water box) to allow the generator to pick up, the usual method is to put the water box blades in, short circuit one of the boxes with a fuse wire, and then to close the circuit breaker and the switches. Then, if the machine starts to pick up and the voltage decreases as soon as the fuse wire burns away, there is too much resistance in the water boxes. They should be salted to decrease the resistance, and the operation repeated. Should the resistance in the boxes be too low, the load will increase very rapidly, and it will be necessary to open the breakers to prevent the machine arcing over between the brushes.

When taking the saturation curve on a direct-current generator, the rheostat data should be obtained. This consists in taking readings of armature voltage, field voltage, and field current at the normal rated voltage of the machine and at half the normal rated voltage of the machine.

"Running Light"

A "running light" reading should be taken with the generator running as a motor as described. The speed-limiting device should be set and the end play adjusted while the machine is running as a motor. The bearing temperature should be read and recorded at the end of the run.

After the above tests have been taken, a high-potential test as described should be applied.

This test is made by running the machine free, as a motor. It is made on most direct-current generators and motors which are given a running test, and occasionally on alternating-current synchronous apparatus.

When running any direct-current machine as a motor, the following procedure should be followed: Set the brushes on mechanical neutral. Be sure that the water box for starting is plugged across the main switch, that the main switch is open, and the blade of the water box is way up. Plug the power to the armature, bring the supply voltage up, close the breaker, and lower the blade of the water rheostat slowly, watching the reading on the line ammeter. If the machine does not start to rotate at a value of current below full load, take off the power and investigate the cause. When the machine is running at rated voltage, close the line switch and raise the blade of the water box again. If the machine runs too fast at normal voltage, pull off the power. The connections should be carefully checked to see that the field is wired properly. It may be that the field is connected directly across the main switch. If such is the case, the field current will fall rapidly as the starting resistance is cut out and the motor will speed up. To test for incorrect wiring in the field, observe the field voltage during starting, because it will drop if the field is incorrectly connected.

When "running light" tests are made on generators, the observations must be made with full load field flux. The potential applied to the armature must be equal to the normal rated voltage of the generator, increased by the IR drop under full load. The IR drop is taken as 4 per cent of the normal voltage for both motors and generators. With this voltage impressed, the field current is varied until normal speed is obtained, when careful readings must be made of armature current, armature voltage, field current, field voltage, and speed.

If the machine in test is a direct-current motor, the voltage applied to the armature should be equal to the normal rated voltage of the motor, less the IR drop under full load. The field current is then adjusted to give normal speed, and electrical readings taken as previously outlined for direct-current generators.

The power supplied to machines running free will equal that absorbed in bearing friction, brush friction, windage, and core loss, when the armature I^2R losses have been subtracted.

In making records of these tests, the Testing Record must clearly show whether the "running light" current consists of the armature current plus the shunt field current or whether it is the armature current alone. **To check this point, open the armature circuit with the shunt field circuit closed and note whether any current is indicated on the ammeter which reads the power supplied. If no current is indicated, the reading indicates the armature current alone, otherwise, the "running light" current is equal to the sum of the armature and field currents.** To obtain the "running light" core loss test, the machine should operate as a shunt motor.

For series-wound motors, the field should be separately excited and extreme care should be taken to see that the motor does not lose its field.

In order to obtain running light core loss upon alternating-current synchronous machines (a class in which synchronous converters are not included because the core loss test on these machines is similar to that on direct-current machines), they should be operated as synchronous motors at the proper frequency and rated voltage. For the best results, both frequency and voltage must have a steady value.

With normal voltage on the armature, the direct-current field should then be varied until minimum armature current is obtained. Readings should be then taken of the current and voltage of all the phases. At minimum input current, unity power-factor is obtained and, therefore, the power to drive such machines will be the volt-ampere input. Wattmeters may be used in addition, to check the volt-ampere readings. This measurement includes friction and windage losses, together with open circuit core losses, plus the I^2R loss in the armature. If the value of the core loss need not be separated from the other losses, the test is useful for checking up load efficiency.

On motor-generator sets, unless otherwise specified in instructions, the following "running light" tests should be made: With direct-current brushes down, running at rated speed from direct-current end with line voltage 4 per cent high as for any generator, and no field on synchronous motor, take and record reading of line voltage and current, field voltage and current, and speed. Continuing to hold line

voltage and speed, bring up the field on the synchronous motor until normal voltage on armature is obtained. Take and record reading of synchronous motor armature volts, field volts, and amperes, together with another set of input readings on generator as before. The difference of these two sets of input readings will be the core loss of the synchronous motor.

Be sure to note on all Test Records whether the "running light" test was taken with machine self or separately excited.

SHORT COMMERCIAL TEST AND ADJUSTMENTS

This test consists of a short commercial test as described above and adjustments made for commutation and compound.

Commutation Adjustments

The generator should be wired for load. All brushes should be sanded to a good fit and their spacing and alignment with the commutator bars should be checked.

With the machine running at normal voltage and speed, the load should be increased by small increments, keeping a close watch on the commutator for

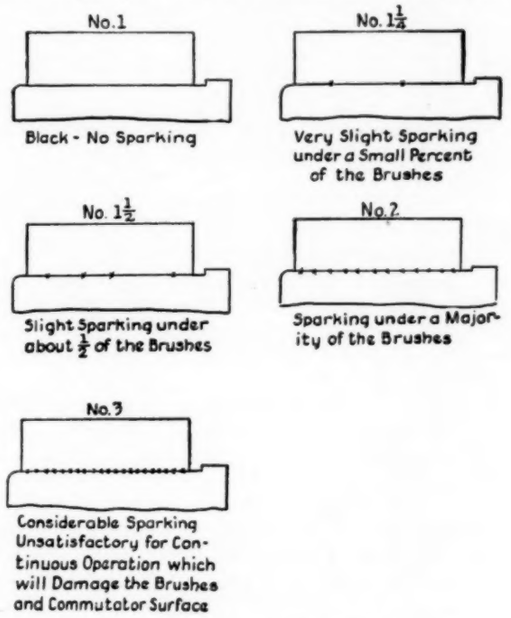
No.1
Black - No Sparking
No. 1¼
Very Slight Sparking under a Small Percent of the Brushes
No. 1½
Slight Sparking under about ½ of the Brushes
No.2
Sparking under a Majority of the Brushes
No.3
Considerable Sparking Unsatisfactory for Continuous Operation which will Damage the Brushes and Commutator Surface

FIG. 2—Degrees of sparking

sparking at the brushes. If no destructive sparking occurs, normal load should be applied to the machine. Commutation may be graded by the chart shown in Fig. 2. After the machine has operated for several hours under full load and the brush fit and polish is good, the required overload should be applied. If no destructive sparking occurs at this load and number one commutation is obtained at normal full load, the adjustment may be considered correct.

If sparking occurs when the machine is loaded, the commutator should be examined for eccentricity and roughness. Any defects found should be corrected by grinding.

If the generator continues to spark after grinding and polishing the commutator, the commutating field is either too strong or too weak. A high-current exciter should be connected in multiple with the commutating field. The strength of the commutating field should then be varied until the correct compensation for sparkless commutation is obtained. This may be permanently corrected by means of a shunt, or by changinng the commutating pole air gap. To determine whether the exciter is bucking or boosting, short circuit the lines from the exciter with about one-quarter load on the test machine. If the meter in the buck and boost circuit reads in the same direction as it did when field was applied to the exciter, the exciter current is bucking the commutating field current. If it reads in the opposite direction, the exciter is boosting.

Adjustments for Compounding

After satisfactory commutation is obtained, the machine should be adjusted for cold compound. The voltage should be adjusted at no load with a falling field, that is, the voltage should be brought considerably above the normal and gradually reduced to normal by cutting in the field rheostat. Then, without changing the position of the field rheostat, normal load should be put on the machine with the speed held constant (unless otherwise specified), and a reading taken at full series field, of the line voltage and current, field voltage and current, and speed. The line voltage should rise considerably above the rated full load voltage of the machine. If it does not rise, but falls, the series field is either weak or reversed. If the whole series field opposes the shunt field, it may be easily checked by tracing out the direction of the current after it leaves the armature. All series field spools are wound in the same direction so that only the general direction around the frame need be traced.

The series field may be wound in an opposite direction to the shunt field. To test this, reverse the series field leads. Should the machine over-compound with the series field in the reverse direction, test should immediately be discontinued until the spools are changed.

It may be that only a part of the series field is reversed. To locate a reverse series spool, it is best to excite the series field up to 20 per cent of full load current, then either try for polarity or make a potential curve, using the series field as a source of excitation. Extremely low voltage will appear on the potential curve, both in front and behind the reverse field.

If the machine over-compounds correctly, the shunt should be placed in the series field and adjusted until the specified compounding is obtained. The no-load point should be taken with a falling field as above, then, without changing the field rheostat, the load should be applied gradually until full load is reached and a reading taken. This process should be repeated until the shunt has been so adjusted that a full load voltage is obtained about one per cent above that specified. This will allow for the voltage drop in the armature due to heating. A compounding curve should then be made, following the values of load given on the data sheet.

Machines which are to be directly connected to prime movers, and which require governors, should have allowance made for the drop in speed from no load to full load.

Series Characteristic

A series characteristic is taken on all series-wound generators. This is done by increasing the load by small steps until full load is obtained, the line current and voltage being recorded at each step. The load is then reduced by small steps to no load, the same readings being taken. A curve is then plotted with the amperes as abscissae and line voltage as ordinates.

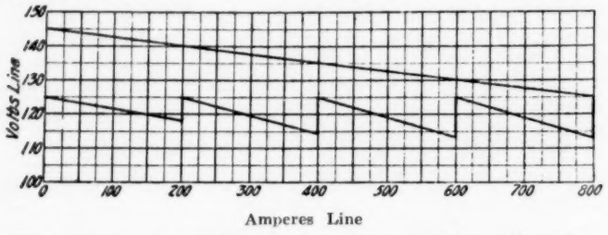

FIG. 3—Shunt regulation of a 6 pole, 100 kw., 600 rpm., 125 volt generator.

Shunt Regulation

Shunt regulation should be taken on shunt-wound generators. A reading should be taken first at no-load normal voltage. Without changing the rheostat, one-quarter load should be thrown on and a reading taken of line current, line voltage, field current, and field voltage. Holding one-quarter load, the voltage should be brought up to normal and the same readings taken. The load should then be increased to one-half full load, with the rheostat in the same position, similar readings taken and the test repeated for three-fourths and full load. With full load on

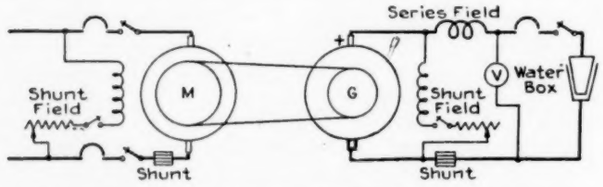

FIG. 4—Connections for loading DC Generator on a water box.

the machine, the voltage should be brought up to normal, and with the field rheostat in this position, the load should be taken off the machine and the rise in voltage observed. All these entries should be made on the Record Sheet. A curve should be plotted with line amperage as abscissae and line voltage as ordinates. See Fig. 3.

Generators of motor-generator sets are quite frequently required to operate as either a motor or generator. These machines are equipped with switches for reversing the series fields in case of motor operation. In order to have the machine operate with the proper speed characteristics as given by the engineering instructions, further adjustments are necessary on the series field. The shunt across the series field that was used for compounding the machine as a generator should also be used in multiple with the shunt used for motor operation.

After final adjustments have been made, the brush-holder yoke should be doweled or trammed.

COMPLETE TESTS

Complete tests on a direct-current generator include the tests mentioned in "Short Commercial Test and Adjustments," in addition to open circuit core loss, normal load heat run, over-load heat run and a hot compound or regulation curve.

Open Circuit Core Loss

There are three methods used to measure the core losses of rotating direct-current apparatus and alternating-current synchronous apparatus. They are as follows: "Running light" core loss, belted core loss, and deceleration core loss.

The following conditions must be obtained with the direct-current apparatus in order to give satisfactory results: The brushes must be shifted on the commutator to the mechanical neutral point. The driving power should be supplied from a variable voltage source that is not subject to sudden fluctuation. Readings must not be taken when the rotating parts are accelerating or decelerating.

Normal Load Heat Run

There are two methods used in the Testing Department for loading direct-current generators. The water box method, familiarly known as the dead-load method, is used only where it is impossible or uneconomical to use the feeding-back method.

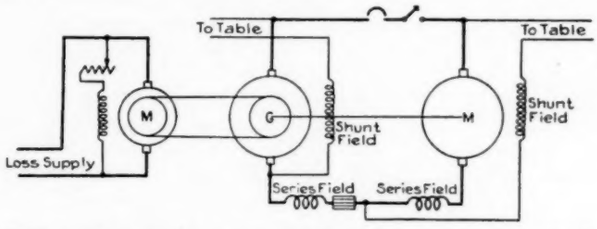

FIG. 5—Connections for mechanical loss supply feed back.

The water box method consists in driving the machine by belted motor or other means and loading it directly upon the water box. See Fig. 4. This method entails considerable expense because all the power generated is lost. On large machines requiring a considerable amount of power to be dissipated, several water boxes are connected in multiple. The standard water box used in the Testing Department is designed to dissipate 75 kilowatts continuously. Care should be taken to have the circulating water in the water boxes so adjusted that violent boiling will not occur, as it is difficult to hold the load constant when this occurs. The load should be evenly divided between the different water boxes.

In order to decrease the loss of power and reduce the cost of testing, the feeding-back method is used when possible, especially with large direct-current machines or motor-generator sets. In this method, the total machine losses are supplied either mechanically or electrically from an external source.

In the mechanical loss supply method, two machines of the same size and voltage should be belted or directly connected together and driven mechanically by a motor large enough to carry the losses of the set. Connections are made as in Fig. 5. If the machines have series fields, the one to operate as a motor should be so connected that it will run as an accumulative compound-wound motor. The voltage of each machine should be brought up as in the case of a generator and the machines thrown together by closing the switch between them when the voltage across it is zero. One machine is then adjusted to act as a motor by weakening its field.

This lowers its generated voltage and causes current to flow, which should be adjusted to the required value. The speed is held constant by the loss supply motor.

In the method of electrical loss supply, two machines are direct connected or belted together, and the losses supplied electrically. See Fig. 6. The machine acting as a generator should be run under normal operating conditions of voltage and current. The speed is held by varying the field of the motor.

Another method of loading machines, which is sometimes used, is to feed back on the main power house supply circuit. If the main supply circuit is likely to vary in voltage, it may be necessary to insert the resistances between the generator and supply. It sometimes happens that the no-load voltage of the generator is below that of the supply. As

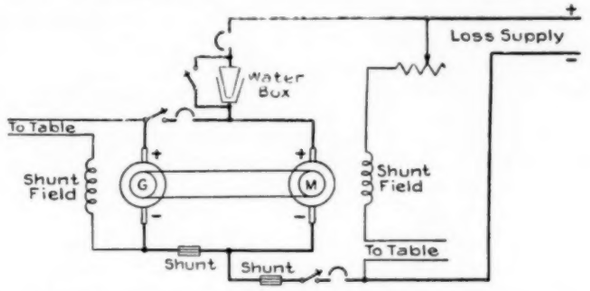

FIG. 6—Connections for electrical loss supply feed back.

changing the line resistances will have no effect at no load, the generator voltage must be increased until it is equal to that of the main supply circuit. Having previously calculated the full load field current from the no-load current and the ratio of compounding voltages, the machines are thrown together and full load put on the generator by cutting out the variable resistances.

Two similar motor-generator sets can be tested very readily by the feeding back method. As an example: suppose each set consists of an induction motor and a direct-current generator. In this case, connections are made as in Fig. 7. The alternating-current and direct-current ends of the respective sets are connected together, one set being run normally and the other inverted. The induction generator pumps back on the induction motor, both taking their exciting current from the alternator A which supplies the losses. They are started, one at a time, from the alternating-current, and the direct-current ends adjusted by means of a voltmeter across switch P. The direct-current motor field is weakened until the ammeter in the direct-current line indicates that normal current is flowing. A weakening of the motor field allows the speed of the inverted set to increase just enough to load the induction generator, while it also decreases the counter e.m.f. of the motor an amount sufficient to allow full-load current to flow in the direct set. This load must be closely watched, as it may be unstable.

After the machine has been properly compounded, the normal load heat run may be started, using one of the methods described for load.

In addition, the brushes and commutators should be in first-class condition, and under no circumstances should a heat run be started until the brushes have at least a 90 per cent fit.

During the heat run, all conditions should remain normal and the line current, voltage, and speed be held as specified on the testing instructions. Field current and voltage should be read. Readings of all instruments and thermometers should be taken and recorded every half hour and commutation should be noted and recorded at every reading during the run. The field current should increase slightly during the run and the field voltage should increase an amount corresponding to the higher temperatures of the field coils and increased field current. When the machine reaches constant temperature, as shown by thermometers, it should be shut down, final temperatures taken of all parts, and the hot resistance of the main field carefully measured. A rise of temperature by the rise in resistance should be calculated by the formula.

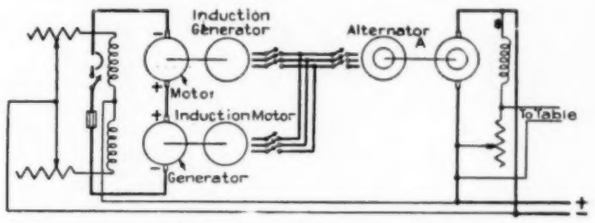

FIG. 7—Connections for Induction motor generator set feed back.

Let RT_2 equal the hot resistance of the copper measured at temperature T_2. RT_1 equal the cold resistance of the copper measured at temperature T_1.

$$\text{Then } T_2 \text{ equals } (234 + T_1)\frac{RT_2}{RT_1} = 234.$$

Overload Heat Run

All overload heat runs require considerable attention. The machines should first be brought to normal load temperatures before the overload is applied. The overload then should be carried only for the specified time, since in many cases the temperature rises rapidly throughout the whole period of the run, and lengthening or shortening this period a few minutes may cause several degrees difference in the final temperatures obtained. On all two-hour overloads, the temperatures should be recorded every half hour. On overloads of a duration shorter than two hours, the temperature should be recorded every fifteen minutes. If the voltage should fall below the rated full load value with normal field, it should be raised and kept at the rated amount during the run. The field voltage and current will increase during the time of the overload.

Hot Compounding Test

After the heat runs have been taken and final temperatures recorded, a hot compounding curve should be taken. The hot compounding test is similar to the cold compounding test, except that the compounding must be adjusted very closely to the value specified on the testing instructions. When this has been done a complete curve should be obtained with readings taken in the following order: No load, full load, three-quarter load, one-half load, one-quarter load, and 125 per cent load. The field rheostat must not be moved from the position for

the no-load setting. A curve should be drawn with the load as abscisae and armature voltage as ordinates.

THREE-WIRE GENERATORS

Some direct-current generators are provided with collector rings for operation on Edison three-wire circuits. The series field and commutating field are usually divided, one-half being placed on each side of the armature as shown in Fig. 7. Tests are made as on other direct-current generators, with the following additional points: In compounding a machine, care should be taken to have the shunts of approximately the same size, in each half of the series field. Volts across collector rings and from collector ring to positive and negative studs, should be measured. If commutating field shunts are used, the same precautions should be taken.

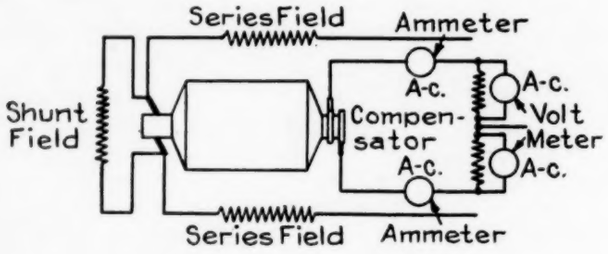

FIG. 8—Three-wire generator.

Unbalanced Readings

If unbalanced readings are required, a compensator should be wired as in Fig. 8. A reading should be taken at no-load normal voltage. With no change in the field, the holding constant speed, one-quarter of the load should be thrown on one side of the line and the voltage read from the neutral to each side of the line, as well as line and field voltage and current. One-quarter load should then be put on the other side of the line, giving a balanced load, and readings taken as before. The load should then be increased to one-half load on one side, this procedure being continued until 125 per cent balance load is obtained and readings have been taken of each step. Instructions sometimes call for a 150 per cent balance reading, in which case the load is increased 50 per cent at each step, instead of 25 per cent.

Revolving Compensator

One type of three-wire generator has its compensator mounted directly on the shaft at the back of the armature and is equipped with only one slip ring.

Flicker tests should be made on all generators of this type to determine whether the compensator is correctly tapped to the armature coils. A lamp of proper voltage should be connected to the neutral, and, in turn, to positive and negative terminals. If the armature is properly tapped, the lamp will burn without flickering.

EXCITERS

Exciters are tested in the same manner as other direct-current generators, previously explained. On direct-connected exciters, the brushes are shifted to obtain the proper compound. On all exciters a normal kilowatt 120 per cent voltage reading should be taken.

Stability Test

Direct-connected exciters should be given a stability test when called for by the engineering instructions. With rated no-load voltage on the alternator, raise and lower the speed 2 per cent above and below normal, noting and recording the voltage change in each case. The change in voltage should not exceed 6 per cent of normal no-load voltage in either case. The no-load voltage setting should always be made with a rising field.

THREE-WIRE BALANCER SETS

During the operation of three-wire circuits, the load often tends to become heavier on one side than on the other, with a consequent unbalancing of the voltage. To relieve this, small motor-generator sets called balanced sets are used.

In its most common form, the balancer set consists of two similar machines on one shaft, or with their shafts coupled together and the armatures connected in series across the outside main. Each machine is wound for half the voltage between the outside mains, and their combined rating in amperes is made equal to the probable unbalance in load between the two sides of the system. This unbalanced load is carried by the neutral wires taken from the balancer sets at the point where the two armatures are connected.

When the load on the system is balanced, the two machines run as motors in series across the outside lines, no work is done, and the only current used is that necessary to overcome the losses of the machines running free.

As soon as one side of the system becomes more heavily loaded than the other, the drop in voltage on this side will be greater, and the voltage impressed on the machine on this side, reduced. The other machine, having a higher voltage, will tend to run faster than the first and drive it as a generator. The machine operating as a motor will act as a load on its side of the system, lowering the voltage on that side, while the generator will supply current to raise the voltage on the heavily loaded side. The combined current of the two machines equals the unbalanced load of the system and the total effect is to restore the voltage balance of the system. As the unbalanced load on the system may shift from one side to the other, this action of the balancer must also shift. Either machine may at any instant be operating as a motor and the next instant as a generator. Since the direction of rotation is always the same, it is impossible to tell without knowing how the load is balanced, which is the motor and which is the generator.

Balancer sets are adjusted by loading one side at a time with the required current in the neutral wire.

Fig. 9 shows the connections for the compound-wound balancer set connected for loading in the Testing Department.

The tests on a three-wire balancer set may be divided into the following groups:

Static—Short Commercial Test and Adjustments —Complete Tests.

STATIC

Static tests include the same tests as taken in the static test on a direct-current generator.

SHORT COMMERCIAL TEST AND ADJUSTMENTS

Short commercial test and adjustments on a three-wire balancer set include saturation on each machine and balancing tests.

Saturation

Saturation may be taken by operating each machine as an individual generator.

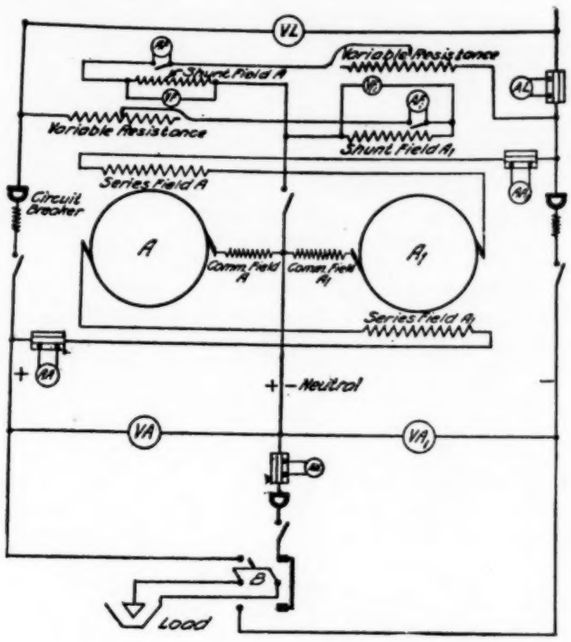

FIG. 9—Wiring diagram for testing balancer set.

Balancing Test

Balancing tests consist of adjusting both machines of the set so that the voltage across each machine shall always be balanced within two per cent, and the sum of the two voltages will be equal to the applied voltages. The wiring on balancer sets must be done as carefully as that for motors, for either end of the set may be operating at any time as a motor. The same precautions, therefore, must be exercised as when operating a motor.

On shunt-wound sets, the fields are cross connected and should be adjusted by shifting the brushes to such a position that the proper voltage balance is obtained. One side of the set is loaded at a time as shown in Fig. 9. Satisfactory commutation and speed must also be obtained. When such a condition has been established with one side running as a generator, the set should be reversed and the other side adjusted to correspond. When both sides have been properly adjusted, the set should operate with either side running as a motor or generator.

It should be noted that on compound-wound balancer sets the machine operating as a motor runs as a differentially-wound machine, while the other acts as an accumulative compound-wound generator. Therefore, care should be taken with an adjustment, because the set may have enough series field to cause it to speed up to a dangerous point.

COMPLETE TESTS

Complete tests on a balancer set include those tests already mentioned under "Short Commercial Test and Adjustments" in addition to core loss, normal and overload heat runs, and "running light" readings.

Core Loss and "Running Light"

Core loss may be taken on a set with three or more bearings, by the method of core loss previously described.

On two-bearing sets, the core loss is obtained by a series of "running light" readings on each machine as follows: With one end operating as a shunt motor, read the input with no voltage on the other.

a. With brushes down
b. With brushes up
c. With normal voltage on the generator end and with brushes down.

These readings should then be repeated with the set reversed. From these readings core loss of the set may be calculated.

Heat Runs

After the set has been adjusted, the heat runs should be taken by loading one side for the specified time with the required current flowing through the neutral wire. All readings of voltage and current should be carefully checked to see that they are consistent.

DIRECT-CURRENT MOTORS

The tests on direct-current motors may be divided into the following groups:

Static Tests—Short Commercial Tests—Short Commercial Test and Adjustments—Complete Tests.

STATIC TEST

The static test on a direct-current motor includes cold resistance measurement, potential drop, polarity of all fields, air gap measurement, and high-potential test.

SHORT COMMERCIAL TEST

A short commercial test on the direct-current motor includes cold resistance measurement, potential drop, polarity of all fields, location of mechanical neutral, "running light," speed limit and end play setting, bearing temperatures, and high-potential tests.

"Running Light"

After drop and polarity have been taken and the brushes set on mechanical neutral, the machine may be started and "running light" readings taken.

In making "running light" tests on adjustable-speed machines, readings should be taken at both extremities of speed, at a voltage 4 per cent lower than the rated voltage of the machine.

The methods used in setting speed-limiting and end play devices have been described previously.

SHORT COMMERCIAL TEST AND ADJUSTMENTS

The tests taken under this heading include those taken under the "Short Commercial Test" in addition to adjusting the machine for commutation and proper speed characteristics.

Adjustments for Commutation

The same method as described on page 459 for commutation adjustment on a direct-current generator, should be used. If the motor is of the adjustable-speed type, the commutation adjustments should be made at the high speed.

Speed Curve

On reversible-speed motors, the machine should be set on electrical neutral. If the motor is of **adjustable speed** type, the neutral setting should be made at high speed. This is done by running the

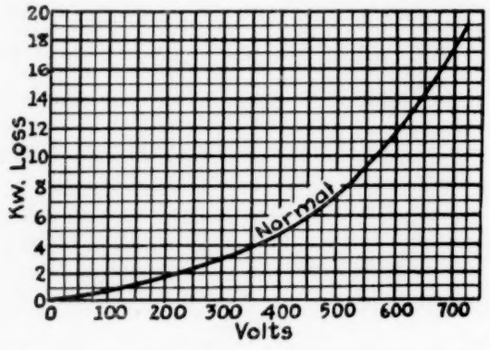

FIG. 10—Open Circuit Core Loss on a 500 K.W., 600 volt, 20 pole, 360 rpm, 3 phase, 60 cycle, Alternating Current Generator.

machine in both directions of rotation with the same field current under full load line current and voltage, shifting the brushes, if necessary, until the speed comes the same in both directions. It may be necessary, if much of a shift from mechanical neutral is made, to re-adjust the machine for commutation.

A strong commutating field will cause a rising speed curve. If the machine has a rising speed characteristic it should be referred to the Engineering Department.

The speed curve should be taken in both directions of rotation at both speeds, in the following manner: Load the machine to full load normal voltage, current, and speed and take readings of volts and amperes line, volts and amperes field; and speed, continuing to hold line volts and field amperes constant take reading at ¾, ½, ¼, and 1¼ load as above. Take the curve in the opposite direction with the same field amperes, line voltage, and current for each load point, taking corresponding readings as before. The two curves should check within limits specified in Engineering Instructions or Standing Instructions.

All self-excited, single-speed motors should be tested at full field.

COMPLETE TESTS

Complete tests on a direct-current motor consist of those mentioned under the "Short Commercial Test and Adjustments," core loss, normal and overload heat run, and hot speed curves.

Core Loss

To check the results of the core loss as the test proceeds, the power input to the driving motor required by the core loss at a given excitation should be plotted against volts armature generated. This should give a curve similar to Fig. 10.

Correct the motor input at various field strengths by deducting the I^2R loss in the armature of the driving motor, and subtracting the power input to the driving motor with zero field on the machine in test. The core losses left correspond to the various field strengths. By subtracting the "running light" input to the driving motor from the input at zero field on the machine in test, the bearing friction and windage losses of the machine under test are obtained.

On series motors, core loss tests should be taken at several different speeds covering the range of the speed curve. The method used is identical with that dscribed above.

NORMAL AND OVERLOAD HEAT RUNS

Mechanical Loss Supply

The connections should be made as shown in Fig. 5 and the machines thrown together. If the motors are compound-wound, the one acting as a generator should have its series field reversed in order to have this machine operate as a cumulative compound generator. In order to load the motor, the field of the generator will need to be increased slightly. The speed of the motor, furnishing losses, must vary according to the speed characteristics of the motor under test.

Electrical Loss Supply

When using the electrical loss supply, the two motors should be wired as shown in Fig. 11. If the

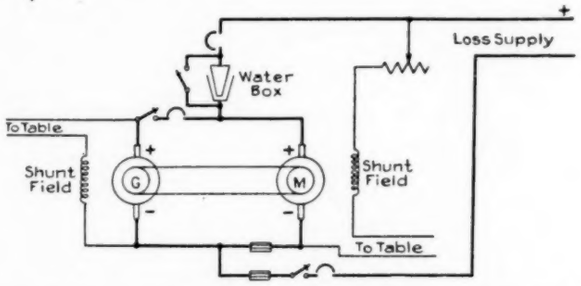

FIG. 11—Connections for electrical loss supply feed back.

motors are compound-wound, the one acting as a generator should have its series field reversed. The motors should be started from the electrical loss supply circuit, and the voltage on the generator adjusted so that there will be zero potential across the switch. The machines then may be thrown together by closing the switch. By increasing the field on the generator, the load can be varied to any value desired. The voltage of the motor should be held at the desired value by means of the loss supply voltage.

After adjustments have been made to obtain the proper speed curve, the heat runs called for by the instructions should be made.

Hot Speed Curve

Hot speed curves are taken after the heat run has been made on the motor. These are taken in the same manner as the cold speed curve, except that the field current obtained at the end of the heat run should be held.

Items of Interest

Edwin L. Wiegand Company, manufacturers of electric heating units, announces the appointment of the Southern Engineering & Supply Company, 2001 North Avenue, Richmond, Virginia, as their sales engineering representative for the state of Virginia.

The Moloney Electric Co., St. Louis, Mo., just completed a very handsome catalog, number 6628. The catalog is illustrated and the views shown give a fair idea of a new and modern transformer plant completed during the year 1927 equipped for building transformers from the smallest to as large as 25,000 KVA and for voltages as high as used by the industry. This plant is the result of the management of the Moloney Electric Company devoting many years of effort towards the development of transformers of the highest standard.

The Cleveland Crane & Engineering Company, Wickliffe, Ohio, have just issued bulletin number C-100. This bulletin describes the Cleveland Arc Welded Roller Bearing Crane. The Cleveland Crane & Engineering Company will be glad to mail a copy of this bulletin on request.

The Ideal Commutator Dresser Company, Sycamore, Illinois, announce the completion of a new tool called the Perfect Tool Rest, which is a portable grinder to be used in conjunction with Ideal Commutator Re-Surfacers. Write Ideal Commutator Dresser Co. for descriptive literature.

The Roller Smith Co., New York, N. Y., announces the appointment of Mr. Elliot E. Van Cleef, 53 West Jackson Blvd., Chicago, Ill., as its District Sales Agent in the Chicago territory. Mr. Michael B. Mathey who has been connected with the Chicago office for many years will be associated with Mr. Van Cleef.

The Farrel-Birmingham Company announce a new and complete series of speed reducers which have Sykes continuous tooth herringbone gears and antifriction bearings. The improvements claimed for this new design of reducer are:

(1) The roller bearings being of the type which combine journal and thrust capacity, both pinion and gear shafts are held from end float and are therefore protected from abuse from connected mechanism.

The Farrel-Birmingham Company claim that this type of mounting is practicable with the Sykes gear since the apices of the teeth are central in the face of the gears around their entire periphery, and no end float of either gear or pinion is necessary.

(2) The mechanical efficiency is increased to between 98½ to 99% for a single reduction and from 98 to 98½% for a double reduction.

(3) The lubrication is simpler than with the plain bearing units since in all cases the same oil may be used for gears and bearings and the splash and flood automatic system of lubrication is possible throughout the whole series.

(4) There is a considerable saving in space.

(5) The roller bearings being interchangeable, it is possible to make the gear units interchangeable and to manufacture them in larger quantities than the plain bearing type units, thereby reducing the initial cost.

The Farrel-Birmingham Company, Buffalo, N. Y., will be glad to mail bulletin on request.

M. H. Detrick Co., Chicago, Ill., manufacturers of Detrick Flat Suspended Arches, Detrick Sectional Supported Air-Cooled Walls and Detrick Soaking Pit Covers, announces that it is now represented in Cincinnati, Ohio, by The Ash Engineering Co., G. C. Parr, 1021 Chamber of Commerce Bldg., Cincinnati, Ohio.

Plans for a new electric car dumper, expected to set a new record for speed, have been completed by the Toledo & Ohio Central Railroad. The new dumper will be built by Heyl & Patterson and is expected to be completed in March, 1929. It will be located at Toledo adjacent to the first all-electric car dumper installed on the Great Lakes, also owned by the T. & O. C. R. R.

The new dumper will be of the lift and turnover type with a variable dumping position; i. e., the car can be raised and dumped at any height between the maximum and minimum pin positions. Complete electric equipment will be supplied by the General Electric Company. The mule haul will be driven by two 500-horsepower, shunt wound, direct-current motors, and the cradle will be driven by two motors of the same type and rating. Control will be of the Ward Leonard (variable voltage) type, incorporating special features to meet the exacting requirements of such service. Both alternating and direct-current motors will be used on the dumper, the total equipment involving an aggregate of approximately 3,000 horsepower.

Power for the operation of the dumper will be purchased from the Toledo Edison Company and will be received at 6600 volts, 3 phase, 60 cycles. This will be transformed down to 440 volts for the operation of the alternating-current motors, and will be converted—by means of two motor-generator sets—to the proper voltage values for the operation of the direct-current equipment.

The Dry Quenching Equipment Corporation, a subsidiary of International Combustion Engineering Corporation, New York, N. Y., has now developed a new type of equipment designed to meet the coke quenching requirements of smaller gas and coke works. It is known as the Sulzer Dry Quencher, Type C. This Dry Quencher possesses the advantages of simplicity of design and operation, careful handling of coke, and low investment cost; and it includes all the advantages of Dry Quenching secured in large installations.

This is new equipment and it is of decided interest to those of you who are identified with industries in which the handling of coke is a problem. A publication which is available will be sent upon request.

Bulletin number 1903, issued by the Reliance Electric & Engineering Company, Cleveland, Ohio, covers questions and answers about "Across the Line Motors." The Reliance Electric & Engineering Company will be glad to forward a copy on request.

"Light and Production" is the title of a new sixteen-page booklet on industrial lighting, especially prepared for the industrial executive. Herein is contained information that every executive should know about the lighting of an industrial plant. Opening with a concise treatment of the benefits of a productive installation, the text continues with chapters on a comparison of light and vision, scarcity of daylight, a means of checking the present lighting system, the fundamentals of good lighting, and the method of securing a Productive Lighting Installation.

The booklet contains many extremely interesting illustrations, is well planned with regard to text and especial attention has been given to appearance and easy readability. Copies may be obtained from the Illuminating Engineering Department of Benjamin Electric Mfg. Co., at 120 South Sangamon Street, Chicago.

The world's largest steam pipe has recently been completed at the South Philadelphia Works of the Westinghouse Electric and Manufacturing Company. It is 7 feet in diameter and is composed of sections of rolled steel which are joined together by arc-welding. It is to be installed in a large power plant and will carry 1,600,000 pounds of steam per hour at 40 pounds absolute pressure.

Gears & Forgings, Cleveland, Ohio, new headquarters for the executive offices, sales, engineering and planning departments have been established at the Cleveland Division. In order to function with the utmost facility and efficiency, a complete modern administration building has been erected. In building this new office Gears and Forgings, Incorporated, have spared no efforts in providing, not only pleasant surroundings, but the finest arrangement of departments to expedite the handling of their business.

A good deal of the success of this company has been brought about by their thorough and painstaking engineering work. They are finding it necessary to do more and more of this work as their customers depend increasingly on them for the engineering of their gear problems.

Appointment of Mr. N. L. Mortensen as Chief Engineer for The Cutler-Hammer Mfg. Co., Milwaukee, has been announced, effective September 1.

Mr. T. E. Barnum, former Chief Engineer, has been appointed Consulting Engineer for the Company, in which position he will be able to give uninterrupted attention to engineering problems and outside engineering relations.

Mr. Mortensen has been connected with Cutler-Hammer for 21 years, the last five of which have been as Assistant to Mr. Barnum. Born in Denmark and receiving his technical education there, and in Germany, Mr. Mortensen's versatility as a Control Engineer has long been recognized by United States Industry. Articles by him have appeared frequently in the technical press and he has delivered numerous papers before electrical societies. He is a fellow of the A.I.E.E. and a member of the A.I.S.E.E. Mr. Mortenson assumes his new post with the best wishes of his host of friends and all the Industry in general.

Mr. F. D. Egan, Electrical Engineer, Lackawanna Plant, Bethlehem Steel Company also a Past President of the A.I.&S.E.E., played his first game of golf with the Managing Director of the A.I.&S.E.E., John F. Kelly at the 1919 Convention in St. Louis. Not very long ago on the Erie Downs Course at Buffalo Egan scored an Ace on number four hole. Egan dropped his drive off of number four tee. In making the shot he used a number four iron the ball hitting near the edge of the green taking a couple of hops and then trickled into the cup. This hole has a yardage of one hundred seventy-five from tee to green. Mr. Egan also won the Jamieson Trophy of the Erie Downs Course defeating W. D. McDonald.

The Reliance Electric & Engineering Co., Cleveland, Ohio, manufacturers of Electric Motors D.C. and A.C., have issued a bulletin No. 103 which describes Type AA Reliance Fully Enclosed Fan-Cooled Induction Motors, for Two and Three Phase Alternating Current Circuits. This bulletin describes the construction and uses of this type of motor and is handsomely illustrated. Write C. V. Putnam, Reliance Electric & Engineering Co., Ivanhoe Road, Cleveland, Ohio, for a copy.

Bulletin No. 2080, Allis Chalmers Manufacturing Co., is a treatise covering the Relative Cost of Transformers. The bulletin is of especial interest to engineers when considering changes or additions to transmission systems.

Changes in the Electrical Department at Follansbee Bros. Plant are as follows: Edward C. Cleary, Chief Electrician, Toronto Plant, Toronto, Ohio; Mr. A. W. Mohrman, Chief Electrician, Follansbee Plant, Follansbee, W. Va.; Mr. J. S. Murray, Chief Electrical Engineer, with offices at Follansbee, W. Va.

Effective October 15, Mr. Walter G. Hildorf will be placed in charge of all metallurgical work for The Timken Steel and Tube Company, Canton, O. For the past several years Mr. Hildorf has been metallurgical engineer for the Reo Motor Car Company, Lansing, Mich.

Mr. O. Needham, one of the Steel Mill Division Engineers with the Westinghouse Electric & Mfg. Co., has accepted a new position with his company. Mr. Needham is now Assistant Manager of all testing.

It is with regret that we announce the death of Mr. H. C. Fairbanks of the General Electric Company.

His death was due to a complication of ailments.

Mr. Fairbanks joined the Association of Iron and Steel Electrical Engineers on September 10, 1917, and for the past eleven years, he has been one of its most active supporters.

In extending our sympathies to his family and friends, we are mindful of the great loss to the iron and steel industry which his death has caused.